DEUTSCHE internationale Zeitschrift

für zeitgenössische Wissenschaft

№133
2026

DIZZW 2020

DEUTSCHE internationale Zeitschrift
für zeitgenössische Wissenschaft

DIZZW 2020

DEUTSCHE internationale Zeitschrift
für zeitgenössische Wissenschaft

ISSN (Print) 2701-8369
ISSN (Online) 2701-8377

Deutsche internationale Zeitschrift für zeitgenössische Wissenschaft

• • •

№133 2026

Deutsche internationale Zeitschrift für zeitgenössische Wissenschaft ist eine internationale Fachzeitschrift in deutscher, englischer und russischer Sprache.

Periodizität: 24 Ausgaben pro Jahr
Format - A4
Alle Artikel werden überprüft.
Freier Zugang zur elektronischen Version des Journals

- Edmund Holst (Salzburg) AT
- Michaela Meissner (Köln) DE
- Klara Amsel (Liège) BE
- Briana French (Cambridge) GB
- Joleen Parsons (Manchester) GB
- Dragomir Koev (Sofia) BG
- Stanislav Štěpánek (Praha) CZ
- Valeriya Kornilova (Kyiv) UA
- Dmitriy Aksenov (Lviv) UA
- Valentin Bragin (Moscow) RU
- Mirosław Bednarski (Warsaw) PL
- Daniela Villa (Florence) IT
- Mattia Molteni (Rome) IT
- Sylwia Krzemińska (Ljubljana) SI
- Käte Kraus (Vienna) AT
- Eleonora Lehmann (Berlin) DE
- Alexander Dressler (Marseille) FR
- Zdzisław Małecki (Warsaw) PL
- Adrián Borbély (Budapest) HU

German International Journal of Modern Science

• • •

№133 2026

German International Journal of Modern Science is an international, German/English/Russian/Ukrainian language, peer-reviewed journal.

Periodicity: 24 issues per year
Format - A4
All articles are reviewed.
Free access to the electronic version of journal.

- Edmund Holst (Salzburg) AT
- Michaela Meissner (Köln) DE
- Klara Amsel (Liège) BE
- Briana French (Cambridge) GB
- Joleen Parsons (Manchester) GB
- Dragomir Koev (Sofia) BG
- Stanislav Štěpánek (Praha) CZ
- Valeriya Kornilova (Kyiv) UA
- Dmitriy Aksenov (Lviv) UA
- Valentin Bragin (Moscow) RU
- Mirosław Bednarski (Warsaw) PL
- Daniela Villa (Florence) IT
- Mattia Molteni (Rome) IT
- Sylwia Krzemińska (Ljubljana) SI
- Käte Kraus (Vienna) AT
- Eleonora Lehmann (Berlin) DE
- Alexander Dressler (Marseille) FR
- Zdzisław Małecki (Warsaw) PL
- Adrián Borbély (Budapest) HU

Artmedia24

Anschrift: Industriestraße 8,74589 Satteldorf Deutschland.

E-mail: info@dizzw.com
WWW: www.dizzw.com

Chefredakeur: Reinhardt Roth

Druck: Einzelfirma Artmedia24, Industriestraße 8,74589 Satteldorf Deutschland

Artmedia24

Address: Industriestrasse 8,74589 Satteldorf Germany.

E-mail: info@dizzw.com
WWW: www.dizzw.com

Editor in chief: Reinhardt Roth

Printing: Artmedia24, Industriestrasse 8,74589 Satteldorf Germany.

Der Redaktionsausschuss der Zeitschrift ist nicht verantwortlich für die veröffentlichten Materialien.

Für den Inhalt der Artikel sind die Autoren verantwortlich
Die Meinung der Redaktion spiegelt nicht unbedingt die Meinung der Autoren wider.

Bei Nachdrucken muss die Zeitschrift zitiert werden.

Das Material wird im eigenen Wortlaut des Autors veröffentlicht.

Editorial board of journal is not responsible for the materials published there.

Authors are responsible for the content of articles.

Opinion of editorial board may not coincide with the opinion of authors.

In case of materials reprinting - link to journal is required.
Materials are publishing in author's edition.

Edition: № 133/2026 (July) – 133th

Passed in press in July 2026

Printed in July, 2026

Printing: Artmedia 24, Industriestrasse 8,

74589 Satteldorf, Germany.

© Artmedia24

© Deutsche internationale Zeitschrift für zeitgenössische Wissenschaft / German International Journal of Modern Science

CONTENT

ECONOMIC SCIENCES

Babunashvili E., Kipiani M.
GEORGIA'S NATIONAL POTENTIAL - A PREREQUISITE FOR A DECENT INTERNATIONAL PARTNERSHIP 4
Bibilashvili L.
ARTIFICIAL INTELLIGENCE AND THE FUTURE OF THE GLOBAL ECONOMY: INSIGHTS FROM THE UNITED NATIONS AI FOR GOOD GLOBAL SUMMIT 6
Svetlin Minev
SECTOR HETEROGENEITY IN THE RELATIONSHIP BETWEEN CORPORATE FINANCIAL PERFORMANCE AND ESG RATINGS OF PUBLIC COMPANIES: A SECTOR-LEVEL REGRESSION ANALYSIS 9
Verigo A.
DEVELOPMENT OF APPROACHES TO THE MANAGEMENT OF THE NATIONAL ECONOMIC SYSTEM (USING THE EXAMPLE OF THE DIGITAL ECONOMY SECTOR).....13
Orjonikidze N., Zhozhuashvili N.
STRATEGIC MANAGEMENT OF CULTURAL TOURISM AS A TOOL FOR SUSTAINABLE TOURISM DEVELOPMENT IN GEORGIA 18

MATHEMATICAL SCIENCES

Frasser C.E.
TOWARD GENERAL CLASSIFICATIONS OF *K*-GEODETIC GRAPHS: STRUCTURAL FOUNDATIONS, ALGORITHMIC CHALLENGES, AND EMERGING RESEARCH DIRECTIONS.....22

MEDICAL SCIENCES

Angelcheva M.
THE WELLNESS CONCEPT IN CONTEMPORARY SOCIETY: CULTURAL AND HEALTH PERSPECTIVES 25
Asadova K., Alosmanova V., Azizova S.
THE ECOBİOLOGY OF MEDİCİNAL PLANTS USED İN THE TREATMENT OF ORAL DİSEASES 30

PEDAGOGICAL SCIENCES

Chipeva M.
WELLNESS AND NUTRITION AS DETERMINANTS OF SPORTS PERFORMANCE 33

SOCIAL SCIENCIES

Dimitrova Bistra
HEALTH PREVENTION IN AQUATIC ENVIRONMENT..38
Tomova T.
CUPPING THERAPY: TYPES, FUNDAMENTAL PRINCIPLES, AND EVIDENCE-BASED APPLICATION TECHNIQUES.....43

TECHNICAL SCIENCES

Amariei Olga-Ioana,
Hamat Codruța-Oana,
Georgevici Gabriela-Felicia,
Chicheș Marian
STATISTICAL MODELING OF THE RELATIONSHIP BETWEEN INSTALLED CAPACITY AND EXPORTED POWER: A CASE STUDY FROM THE BANAT REGION .49
Ildırımzade Yusif
OPTIMIZATION OF DYNAMIC OBSTACLE AVOIDANCE ALGORITHMS FOR AUTONOMOUS MOBILE ROBOTS ON UNEVEN TERRAIN.....57
Yernur Demessin, Darkhan Zholtayev
EVALUATION OF KNOWLEDGE GRAPH INTEGRATION IN LLM-BASED FINANCIAL CHATBOTS 61

VETERINARY SCIENCES

Gerilovych A., Korovin I., Vashchyk Ye.
PCR-BASED DETECTION OF AUJESZKY'S DISEASE VIRUS (SUID ALPHAHERPESVIRUS 1) USING EVAGREEN REAL-TIME PCR ASSAY 68

ECONOMIC SCIENCES

GEORGIA'S NATIONAL POTENTIAL - A PREREQUISITE FOR A DECENT INTERNATIONAL PARTNERSHIP

Babunashvili E..
Associate Professor,
Central University of Europe, Georgia
Kipiani M.
Associate Professor,
Central University of Europe, Georgia
DOI: 10.5281/zenodo.21836910

Abstract

In modern conditions, the irreversible process of globalization has presented humanity with completely new challenges and requirements. Along with a number of positive events and innovations that significantly contribute to the convergence, mutual fusion and integration of the economies of states, there are, accordingly, challenges and threats that are characteristic of the transnational economy: increased unemployment, inflation, social polarization, the collapse of the economic borders of sovereign states, etc. Such processes lead to crises in both socio-economic and public and political relations.

An important and main component of the world economy is precisely the national economies of individual countries. In the process of transformation, they take on completely new functions. Obviously, it is not easy to adapt to a rapidly changing environment and "painlessly" engage in global world economic processes. The main interest and goal of any state is to maintain national security, which is significantly hindered by the forceful dominance of large states. For countries with small economies, this issue is a key and quite painful topic.

With its geopolitical location, ancient traditions of agricultural life, diversity of skills and history, Georgia's national potential can boldly provide a worthy international partnership. It should be considered that against the backdrop of quite a few challenges and difficulties, this will not be an easy process. Accordingly, the country must be reasonably prepared in many ways to meet this most important factor.

Keywords: globalization, integration processes, national economy, power dominance of great powers

At the turn of the 20th and 21st centuries, humanity faced new challenges, which were determined by the irreversible processes of globalization.

Globalization is a multifaceted category that contributes to the expansion of relations between states, the formation of a single information space, a world market for capital and labor. The internationalization of ecological and social problems leads to the practical implementation of the concept of sustainable development.

When assessing world globalization and integration processes, it is important to consider the development of two non-opposite directions of events: on the one hand, globalization accelerates economic development and the consolidation of all humanity, where trade and new technologies, financial capital, information, etc. contribute to the rapprochement of regions of many countries. On the other hand, globalization, transnational economy is accompanied by an increase in unemployment, inflation, strengthening of social polarization processes in society, the blurring of economic borders of sovereign states and a number of other problems that lead to crises of socio-economic and public-political relations.

The main component of modern international relations and the world economy is precisely the national economy. Under the conditions of globalization, a process of transformation of state functions is underway, as a result of which the state acquires new functions, the most important of which is adaptation to the rapidly changing environment and the implementation of national security goals in accordance with the economic and political interests of the state in the global world, which implies the strengthening of differences between countries and, accordingly, the identification of small nations.

The peculiarities of the transition period to market relations, the strategy and tactics of the country's socio-economic and socio-political transformation require an analysis of the role and significance of modern processes, as they affect the formation of the national economy, its effective functioning and security, which should ensure the establishment of healthy economic relations in Georgia and their implementation in the interests of the country. This will become possible when the Georgian economy actually returns to its centuries-old traditional, religious principles and the foundations of Christian morality of economic activity.

The current socio-economic, socio-political, cultural and intellectual situation in our country, despite a number of reforms, is still unsatisfactory and is characterized by certain negative trends: the imperfection of state management structures, the neglect of national goals, cultural achievements and state interests or their replacement by foreign surrogates.

Today, the world is a global mess, but this does not mean that large countries should absorb the culture, spiritual or national values of small countries in order to create a single and faceless culture. As is known, the spiritual and national values of small nations, their diversity enrich the world and eliminate conflicts and

confrontations. However, at the same time, it is necessary to form a moral compass of human values, which promotes dialogue between civilizations.

In the context of deepening market relations, the preservation of national economic policies by individual states, the avoidance of negative aspects of globalization, and the achievement of positive results should be based on the aspiration of all countries towards cooperation, where the development of traditional economies, the fair distribution of accumulated wealth, and the eradication of poverty are important.

Under the influence of extremely complex and rapid processes of globalization, a number of states are forced to conduct national economic policies considering international competitive requirements, which is why small and underdeveloped countries are losing their economic sovereignty and the degree of political independence. Therefore, a reasonable socio-economic policy pursued in our country should neutralize the possible and expected negative consequences of globalization, preserve, develop, and strengthen national identity and security.

For Georgian statehood, it is important not only to determine the historical duration of the nation's identity, but also to clarify what part of the national heritage is useful for future reconstruction. A heritage that was created and formed on the basis of the will of the nation, as Saint Ilia the Righteous (Chavchavadze) says, - national heritage is the same "economic structure, economic order."

Given the need to strengthen the role of the state, state structures regulating the economy should have a particularly cautious and moderate attitude towards the entry of transnational companies into our country, in terms of assessing the state budget and employment of the population, since highly profitable foreign enterprises are eroding the soil and making national production uncompetitive.

In our opinion, the formation of the directions of the national economy, the development of its development concept, doctrine and effective implementation should be carried out in compliance with synergistic principles; the strategy of socio-economic development of Georgia should be based on the affirmation of national statehood and the creation of real guarantees of a life commensurate with that of developed countries for the population, which is achieved by establishing an appropriate system integrated into world relations and building an independently functioning Georgian state based on our traditions, modern technologies and achievements.

Finally, our current life requires society to develop a correct position on many very painful problems and to find a reasonable solution to them. The main thing is that in the course of modern processes we must clearly understand where the subject is and where the object is. The object is very often nations, and this subject tries to impose its ideas on this object and remove the national-moral, spiritual achievements, values that this small people have accumulated over the centuries. This is very dangerous for us. We must know what is acceptable and what is not, what is pseudo-culture.

Small states are often under the supervision of large states, and forceful policies often dominate international relations. The fact is that such policies will be harmful in the conditions of globalization. All countries must consider that if globalization and integration are perceived only as the power of the strongest, it will not bring stability. On the contrary, tension will engulf the world. To prevent this from happening, possible negative manifestations of globalization must be eliminated: the policy of domination must be replaced by a policy of mutual trust, cooperation and negotiations, and conflict or defensive tactics must be transformed into a fair, mutually beneficial and constructive dialogue. Our country needs to be more prepared to face these processes, which means that globalization is inevitable and involvement in it is inevitable, but reasonable and civilized economic adaptation and implementation are important, which will be beneficial both for the national country and for the global challenges of the world.

References

1. Movsesian A., Ognetsev S. World Economy, 2009
2. Krugman, Paul R., Obstfeld, Maurice and Melitz, Marc J. International economics: theory & policy, 2017

ARTIFICIAL INTELLIGENCE AND THE FUTURE OF THE GLOBAL ECONOMY: INSIGHTS FROM THE UNITED NATIONS AI FOR GOOD GLOBAL SUMMIT

Lia Bibilashvili
Professor
Gori State University, Georgia
DOI: 10.5281/zenodo.21836954

Abstract

Artificial Intelligence (AI) has emerged as one of the most influential drivers of economic transformation in the twenty-first century, reshaping production systems, labor markets, international trade, and global governance. The rapid diffusion of AI technologies is creating unprecedented opportunities for productivity growth and innovation while simultaneously generating new economic, social, and regulatory challenges. This article examines the future of the global economy through the perspective of the United Nations AI for Good Global Summit, which has become one of the leading international platforms promoting the responsible and inclusive development of artificial intelligence. Rather than treating AI solely as a technological innovation, the article argues that it represents a structural force capable of redefining global economic governance, competitiveness, and sustainable development. The study analyzes AI's contribution to economic growth, the transformation of international competitiveness, and the emerging governance architecture designed to ensure that technological progress serves global public interests. It further discusses the principal risks associated with AI adoption, including labor market disruption, digital inequality, market concentration, and regulatory fragmentation. The article concludes that while artificial intelligence possesses enormous potential to stimulate global prosperity, its long-term contribution will depend on coordinated international governance, investment in human capital, and policies that balance innovation with inclusiveness and ethical responsibility.

Keywords: Artificial Intelligence; Global Economy; AI for Good Global Summit; United Nations; Digital Economy; Economic Growth; AI Governance; Sustainable Development; Innovation; Global Competitiveness.

Introduction

Artificial Intelligence has become one of the defining technologies of the Fourth Industrial Revolution, transforming the way economies produce goods and services, allocate resources, and generate innovation. Unlike previous technological breakthroughs, AI possesses the capacity not only to automate routine activities but also to perform increasingly sophisticated cognitive functions, including data analysis, prediction, language processing, and decision support. Consequently, AI is reshaping virtually every sector of the global economy, from manufacturing and finance to healthcare, education, agriculture, and public administration.

The growing economic significance of AI extends beyond productivity improvements. Governments increasingly regard artificial intelligence as a strategic asset capable of determining future economic competitiveness, national security, and geopolitical influence. Investment in AI research, digital infrastructure, and advanced computing has become a priority for both developed and emerging economies. At the same time, concerns regarding employment, ethical standards, cybersecurity, data governance, and unequal technological access have intensified debates surrounding the need for international regulatory cooperation.

In response to these developments, the United Nations, through the International Telecommunication Union (ITU) and numerous partner organizations, established the AI for Good Global Summit as a global platform dedicated to ensuring that artificial intelligence contributes to sustainable development and the achievement of the United Nations Sustainable Development Goals (SDGs). The Summit emphasizes that technological progress should not be measured exclusively by economic performance but also by its capacity to improve human well-being, reduce inequalities, and address global challenges such as climate change, healthcare accessibility, food security, and disaster management.

This article argues that the AI for Good Global Summit represents more than a forum for technological discussion. It reflects an evolving model of global economic governance in which international organizations seek to shape the future development of AI through cooperation, ethical principles, and policy coordination. By examining the economic implications of AI through the priorities advanced at the Summit, the article explores both the opportunities and the challenges associated with the integration of artificial intelligence into the global economy.

Artificial Intelligence as a New Driver of Global Economic Growth

Economic growth has traditionally depended on the interaction of labor, capital, and technological progress. Artificial intelligence is transforming each of these components simultaneously. By automating repetitive tasks, enhancing decision-making processes, and enabling predictive analytics, AI significantly increases productivity while reducing operational costs across multiple sectors. Unlike earlier automation technologies that primarily replaced manual labor, contemporary AI increasingly complements highly skilled professions by improving efficiency in knowledge-intensive industries such as finance, medicine, legal services, scientific research, and engineering.

The economic impact of AI extends beyond firm-level productivity. AI contributes to the creation of entirely new industries and business models based on

data-driven innovation. The expansion of digital platforms, intelligent manufacturing, autonomous systems, and generative AI applications demonstrates that artificial intelligence is becoming a central source of value creation within modern economies. Countries capable of developing robust AI ecosystems are therefore likely to experience higher rates of innovation, greater investment attractiveness, and improved international competitiveness.

Artificial Intelligence and the Transformation of Global Competitiveness

The emergence of artificial intelligence is fundamentally altering the determinants of international competitiveness. Classical economic theories emphasized comparative advantage based on labor costs, natural resources, and capital accumulation. In contrast, the digital economy increasingly rewards countries capable of generating knowledge, developing advanced algorithms, managing large-scale data resources, and maintaining sophisticated computational infrastructure.

This transformation has intensified international competition for technological leadership. Major economic powers - including the United States, China, and the European Union have adopted comprehensive AI strategies designed to strengthen domestic innovation ecosystems while reducing dependence on foreign technologies. Investment in semiconductor production, cloud computing, quantum technologies, and digital infrastructure has become an essential component of long-term economic policy. Consequently, technological capacity is emerging as a new dimension of economic sovereignty.

Artificial intelligence is also reshaping international trade by increasing the importance of digital services and cross-border data flows. AI-powered logistics, predictive supply-chain management, and automated customs procedures improve trade efficiency while reducing transaction costs. Nevertheless, these developments also raise important regulatory questions concerning data protection, cybersecurity, intellectual property rights, and digital taxation. As economic activity becomes increasingly data-driven, international cooperation will be essential for establishing common standards capable of supporting both innovation and fair competition.

The United Nations AI for Good Global Summit and the Evolution of Global Economic Governance

The rapid expansion of artificial intelligence has demonstrated that technological innovation alone is insufficient to ensure sustainable and inclusive economic development. As AI increasingly influences global production, trade, finance, and public administration, effective governance has become an essential component of economic policy. The United Nations AI for Good Global Summit represents one of the most significant international initiatives addressing this challenge by promoting cooperation among governments, international organizations, academia, the private sector, and civil society.

Unlike many technology conferences that primarily focus on commercial innovation, the AI for Good Global Summit emphasizes the social and economic implications of artificial intelligence. Its discussions extend beyond technological advancement to include ethical governance, human rights, digital inclusion, healthcare, education, environmental sustainability, disaster risk reduction, and economic resilience. This broader perspective reflects an important shift in international policy thinking: AI is no longer viewed merely as an emerging technology but as a strategic instrument capable of influencing the future architecture of the global economy.

One of the Summit's most important contributions lies in its support for multilateral cooperation. Artificial intelligence operates across national borders through digital platforms, cloud computing, and global data networks. Consequently, fragmented national regulations may create legal uncertainty, increase compliance costs, and reduce international innovation. The Summit therefore promotes dialogue aimed at developing common principles for responsible AI governance while respecting national policy priorities.

The Summit also recognizes that the benefits of AI should not remain concentrated among technologically advanced economies. Developing countries often face significant barriers, including insufficient digital infrastructure, limited research capacity, shortages of skilled professionals, and restricted access to computational resources. Addressing these disparities is essential for ensuring that artificial intelligence contributes to inclusive global economic development rather than reinforcing existing inequalities.

Economic Risks and Challenges of Artificial Intelligence

Despite its transformative potential, artificial intelligence presents several economic risks that require careful policy consideration. Perhaps the most widely debated challenge concerns labor market transformation. AI-driven automation is expected to replace numerous routine and repetitive tasks while simultaneously increasing demand for highly skilled workers capable of designing, managing, and applying advanced technologies. This transition may generate structural unemployment in certain sectors and widen income inequality if workforce adaptation fails to keep pace with technological change.

Another major concern involves the growing digital divide between developed and developing economies. Countries possessing advanced technological infrastructure, substantial research investment, and highly skilled human capital are likely to capture a disproportionate share of AI-generated economic benefits. Conversely, nations with limited digital capacity may experience declining international competitiveness and increasing dependence on foreign technologies. Such asymmetries risk deepening global economic inequalities and reducing opportunities for sustainable development.

Market concentration represents an additional challenge. The development of sophisticated AI systems requires extensive computational resources, high-quality datasets, and substantial financial investment. As a result, a relatively small number of multinational technology companies currently dominate the global AI ecosystem. This concentration may reduce market

competition, limit innovation among smaller firms, and increase dependence on a handful of digital platforms. Policymakers therefore face the difficult task of encouraging innovation while maintaining fair competition and preventing excessive market power.

Finally, regulatory fragmentation remains one of the most pressing obstacles to the responsible development of artificial intelligence. Countries are adopting different legal approaches concerning data protection, algorithmic transparency, intellectual property, cybersecurity, and AI liability. While regulatory diversity reflects national priorities, inconsistent rules may hinder cross-border cooperation and increase uncertainty for businesses operating internationally. The absence of globally accepted governance standards underscores the importance of continued international dialogue through institutions such as the United Nations.

Conclusion

Artificial intelligence is reshaping the global economy at an unprecedented pace, creating new opportunities for innovation, productivity, and sustainable development while simultaneously generating complex economic and governance challenges. As AI becomes increasingly integrated into production systems, labor markets, and international trade, its influence extends beyond technological advancement to the broader structure of global economic governance.

The United Nations AI for Good Global Summit illustrates the growing international recognition that the future of artificial intelligence must be guided by cooperation, ethical responsibility, and inclusive development. By bringing together governments, international organizations, academia, and the private sector, the Summit provides an important platform for addressing the opportunities and risks associated with AI while promoting solutions that align technological progress with the Sustainable Development Goals.

The analysis presented in this article demonstrates that the economic impact of artificial intelligence will depend not only on the speed of technological innovation but also on the quality of governance frameworks supporting its development. Investment in human capital, digital infrastructure, international cooperation, and responsible regulation will be essential to ensuring that AI contributes to sustainable and equitable economic growth. Ultimately, artificial intelligence should be regarded not merely as a technological revolution but as a transformative force capable of redefining the future of the global economy through innovation, collaboration, and inclusive governance.

References

1. Brynjolfsson, E., Li, D., & Raymond, L. R. (2023). Generative AI at work. National Bureau of Economic Research Working Paper No. 31161.

2. European Commission. (2024). AI Innovation Package. https://digital-strategy.ec.europa.eu

3. International Monetary Fund. (2024). Gen-AI: Artificial Intelligence and the Future of Work. IMF Staff Discussion Note.

4. International Monetary Fund. (2025). World Economic Outlook: Navigating Global Divergences. International Monetary Fund.

SECTOR HETEROGENEITY IN THE RELATIONSHIP BETWEEN CORPORATE FINANCIAL PERFORMANCE AND ESG RATINGS OF PUBLIC COMPANIES: A SECTOR-LEVEL REGRESSION ANALYSIS

Svetlin Minev
Assistant Professor
University of Economics – Varna
Knyaz Boris I Blvd 77, 9002 Varna, Bulgaria
DOI: 10.5281/zenodo.21836987

Abstract

This study examines whether the relationship between corporate financial performance (CFP) and environmental, social, and governance (ESG) ratings varies across Global Industry Classification Standard (GICS) sectors. Using ESG ratings from LSEG Data & Analytics and financial data from Yahoo Finance for a sample of 748 publicly listed companies, the study estimates separate OLS regressions of the Total ESG score on ten financial, valuation, ownership, and firm-characteristic variables within each of the eleven GICS sectors. The results reveal substantial heterogeneity: Information Technology and Healthcare show the highest explanatory power ($R^2 = 0.54$ each), followed by Industrials ($R^2 = 0.49$), while the Consumer Discretionary model is not statistically significant ($R^2 = 0.08$). Market capitalisation is the most consistent positive predictor across sectors, while the P/S ratio and ownership concentration are consistently negative where significant. The findings indicate that the CFP–ESG relationship is not uniform but strongly conditioned by sector-specific structural and ownership characteristics.

Keywords: ESG ratings; corporate financial performance; GICS sectors; sector heterogeneity; regression analysis; LSEG.

1. Introduction

The relationship between corporate financial performance (CFP) and environmental, social, and governance (ESG) ratings is widely studied, yet the majority of empirical work examines only one direction - whether ESG performance improves financial outcomes - while the reverse channel, whether CFP shapes ESG ratings, remains less explored [1]. Existing evidence on this reverse channel is also predominantly aggregate, obscuring the possibility that the relationship differs across industries, because firms in different GICS sectors face different regulatory pressures, stakeholder expectations, and resource endowments, all of which plausibly condition how and whether CFP translates into ESG ratings. This study explores whether the relationship between CFP and ESG ratings varies across GICS sectors, by comparing regression models for each GICS sector.

2. Literature Review

The bidirectional ESG–CFP relationship rests on several theoretical foundations. Stakeholder theory provides the conceptual basis for a positive link, holding that firms serving the interests of all stakeholders build the reputation and trust that translate into better financial outcomes [1]. Resource dependence theory adds that a firm's strategy and behaviour are shaped by its reliance on external resources, so that effective ESG management can reduce dependence on the external environment and support long-term sustainability [2]. The slack resources theory posits that firms with stronger financial performance accumulate discretionary resources that can be channelled into ESG activities, providing a direct rationale for a positive CFP-to-ESG link [2]. Signalling theory, extended from its labour-market origins [3] to contexts of information asymmetry generally [4], frames ESG disclosure as a signal: firms with strong ESG performance disclose more extensively to advertise their achievements, while weaker performers restrict or obscure disclosure [5]. Agency theory contributes a governance-focused explanation, whereby the governance component of ESG ratings mitigates principal–agent conflicts and associated monitoring costs, indirectly reinforcing financial performance [6, 7]. Shareholder-supremacy theory, by contrast, treats shareholder wealth maximisation as the firm's primary objective and is often cited as an obstacle to fuller adoption of ESG principles, although a growing body of work seeks to reconcile the two perspectives [8].

Most empirical studies examine the ESG-to-CFP direction with mixed results: meta-analyses report average correlations around 0.09–0.12 [9, 10], a magnitude indicating association rather than economic significance. Gillan et al. [11] show that the ESG–CFP link depends on country characteristics, board composition, and sector - technology and consumer-goods firms are typically rated higher than energy and heavy-industry firms - and conclude there is no scholarly consensus given this variation. Halid et al. [12] similarly conclude, after reviewing studies using LSEG ESG ratings, that the relationship remains uncertain and highly dependent on the financial performance measure used. The reverse, CFP-to-ESG direction has received markedly less attention. Testa and D'Amato [13] find that prior-year financial performance affects environmental-management adoption among Italian manufacturers. Crespi and Migliavacca [14] show that size and profitability drive ESG improvement among financial firms, while Hamdi et al. [15] report a positive ROA–ESG association among US firms. Priyanto and Suhandi [16] find no consistent CFP–ESG relationship among Indonesian energy firms. Giese and Shah [17], using MSCI ratings, document that the financial edge of higher-rated firms is not uniform across sectors, holding in eight of the sectors they examine. This sectoral variation, combined with the limited attention paid to the CFP-to-ESG direction, motivates the present analysis.

Building on this evidence, the present study focuses on the CFP-to-ESG direction and asks whether it is sector-dependent. Two hypotheses follow:

H1. The relationship between corporate financial performance and ESG ratings is heterogeneous across GICS sectors, in both the explanatory power of the model and the sign of individual predictors.

H2. Firm size (market capitalisation) is positively associated with ESG ratings across GICS sectors.

3. Data and Methodology

The sample includes companies with a market capitalisation exceeding USD 2 billion as of 31 March 2025, drawn evenly from all eleven GICS sectors (68 companies per sector, n = 748). Financial and market data are extracted from Yahoo Finance via Python (yfinance, pandas), while ESG ratings are obtained from LSEG Data & Analytics. The dependent variable is the composite Total ESG rating. The independent variables comprise company size (market capitalisation), profitability (ROA, operating margin, net margin), market valuation (P/S and P/B ratios), 5-year stock return, insider and institutional ownership, and the Piotroski F-score. All independent variables except the Piotroski F-score are winsorised at the 1st and 99th percentiles to limit the influence of extreme values, which are pronounced for market capitalisation, the P/S and P/B ratios, and five-year returns. Market capitalisation is log-transformed to reduce scale effects, and all continuous independent variables are standardised (z-scores) so that coefficients are comparable and interpretable as the change in the ESG rating associated with a one-standard-deviation change in the predictor; the ESG rating itself, bounded on a 0–100 scale, is not standardised. A separate regression model is estimated within each GICS sector:

$$TotalESG_s = \beta_0 + \beta_1\, ln(MCap)_s + \beta_2\, ROA_s + \beta_3\, OM_s + \beta_4\, NM_s + \beta_5\, 5ypf_s + \beta_6\, P/B_s + \beta_7\, P/S_s + \beta_8\, IndrO_s + \beta_9\, InstO_s + \beta_{10}\, P\_F_s + \varepsilon_s \quad (1)$$[1]

Models are estimated by ordinary least squares in Python (NumPy, pandas, statsmodels). Overall model validity is assessed via the F-test at $\alpha = 0.05$; individual coefficients are evaluated via t-tests at the same threshold. The Breusch–Pagan test [18] is applied to test for heteroskedasticity, with robust standard errors used where the null of homoskedasticity is rejected; the variance inflation factor (VIF) is used to test for multicollinearity, with values above 10 treated as problematic. A sector is classified as exhibiting a robust CFP–ESG association only if its regression model is statistically significant and contains at least two independent variables with a positive and statistically significant coefficient.

4. Results

Estimating the model separately within each GICS sector reveals pronounced heterogeneity in both explanatory power and coefficient significance (Table 1). Information Technology and Healthcare post the highest explanatory power ($R^2 = 0.54$ each), followed by Industrials ($R^2 = 0.49$); the remaining seven sectors range between $R^2 = 0.19$ and $R^2 = 0.43$, with generally weaker and less consistent associations. The Consumer Discretionary is the only sector whose model is not statistically significant ($R^2 = 0.08$, $p(F) = 0.137$). In Information Technology, two coefficients are significant and negative: the P/S ratio ($\beta = -13.6$), insider ownership ($\beta = -4.2$), indicating that ownership concentration is associated with lower ESG ratings in the sector; market capitalisation is positive but insignificant ($\beta = 2.8$, $p = 0.14$). In Healthcare, four coefficients are significant: market capitalisation is positive ($\beta = 4.75$), while the P/S ratio ($\beta = -4.38$), five-year return ($\beta = -3.27$), and institutional ownership ($\beta = -3.21$) are negative. In Industrials, five coefficients are significant, with market capitalisation ($\beta = 6.81$), the P/B ratio ($\beta = 4.44$), and net margin ($\beta = 5.00$) positive, and the P/S ratio ($\beta = -8.78$) and insider ownership ($\beta = -3.66$) negative. In Consumer Discretionary, the only significant predictor is operating margin ($\beta = 10.94$); the P/S ratio is marginal ($\beta = -5.97$, $p = 0.056$).

Table 1

Sector-Level Regression Summary (n = 68 per sector)

GICS Sector	R^2	F	p(F)	Sig. coeff. (5%)
Information Technology	0.54	8.74	<0.001	2
Healthcare	0.54	8.72	<0.001	4
Industrials	0.49	7.44	<0.001	5
Consumer Staples	0.43	6.02	<0.001	3
Communication Services	0.42	5.90	<0.001	5
Financial Services	0.37	5.01	<0.001	3
Materials	0.28	3.58	0.001	2
Real Estate	0.28	3.56	0.001	3
Utilities	0.27	3.46	0.001	3
Energy	0.19	2.62	0.011	1
Consumer Discretionary	0.08	1.58	0.137	1

Beyond overall model fit, the individual coefficients clarify which predictors drive these associations. Table 2 reports, for each sector, only the standardised coefficients significant at the 5% level, allowing the sign and relative magnitude of each effect to be compared across sectors. Read by column, two regularities

[1] ln(MCap) - Natural logarithm of the company's market capitalization ; ROA - Return on assets; OM - Operating margin; NM - Net margin; 5ypf - Five-year return on stocks; P/B - Price-to-book ratio; P/S - Price-to-sales ratio; IndrO - Insider ownership; InstO - Institutional ownership; P_F - Piotroski F-score

stand out: (log) market capitalisation is positive in every sector in which it is significant, while the P/S ratio and insider ownership are negative wherever they are significant.

Table 2

Statistically Significant Standardised Coefficients by GICS Sector ($p < 0.05$)

GICS Sector	MCap	ROA	OM	NM	5ypf	P/B	P/S	IndrO	InstO	R^2
Information Technology	–	–	–	–	–	–	−13.60***	−4.20**	–	0.54
Healthcare	4.75***	–	–	–	−3.27**	–	−4.38***	–	−3.21**	0.54
Industrials	6.81***	–	–	5.00**	–	4.44**	−8.78***	−3.66*	–	0.49
Consumer Staples	5.93*	–	–	–	−4.87*	–	–	−7.04**	–	0.43
Communication Services	8.11**	6.81*	−8.72*	–	–	–	−12.27***	–	−7.16***	0.42
Financial Services	–	–	6.00*	–	–	–	−12.84***	−4.06*	–	0.37
Materials	6.95*	–	9.16*	–	–	–	–	–	–	0.28
Real Estate	6.89***	–	–	–	–	–	−5.78*	–	5.45***	0.28
Utilities	5.90***	–	–	–	−4.91*	–	–	–	−4.12*	0.27
Energy	8.15**	–	–	–	–	–	–	–	–	0.19
Consumer Discretionary	–	–	10.94*	–	–	–	–	–	–	0.08

Note. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Materials is estimated with HC3 heteroskedasticity-robust standard errors (Breusch–Pagan null rejected); all other sectors use classical standard errors.

Applying the classification criterion - a statistically significant model with at least two positive and significant coefficients - only Industrials qualifies (market capitalisation, P/B, and net margin). Information Technology has no significant positive coefficient, and Healthcare satisfies the criterion for only one variable (market capitalisation). This indicates that, although Information Technology and Healthcare show the highest explanatory power among all sectors, that power is driven predominantly by negative associations - with ownership structure and market valuation - rather than by a positive financial-performance channel; a robust, multi-variable positive CFP–ESG association holds consistently only within Industrials.

5. Discussion

The results reveal substantial sector-specific variation in the strength and direction of the CFP–ESG associations: explanatory power ranges from a non-significant model in Consumer Discretionary ($R^2 = 0.08$) to $R^2 = 0.54$ in Information Technology and Healthcare, and the sign of individual coefficients frequently reverses across sectors. Market capitalisation carries a positive coefficient in ten of the eleven sectors - Financial Services being the sole exception - and is statistically significant in eight of them. In Information Technology it is positive but insignificant ($\beta = +2.8$, $p = 0.14$). This is consistent with slack resources theory: larger firms possess the financial, human, and organisational resources needed for ESG initiatives, and face greater regulatory and public scrutiny that reinforces sustained ESG investment [12, 19]. By contrast, the P/S ratio is negatively associated with ESG ratings in every sector where it is significant, including Information Technology and Industrials. High market multiples typically reflect investor expectations of rapid growth, which may correspond to strategies weighted toward short-term shareholder returns rather than long-term sustainability investment. Ownership concentration is also consistently negative, suggesting that concentrated ownership can weaken the disclosure and accountability incentives that support higher ESG ratings, a pattern most pronounced in Information Technology [20]. Taken together, these results support H1: the CFP–ESG relationship is heterogeneous across sectors in both explanatory power and the sign of individual predictors.

The variation in model fit and coefficient signs across sectors indicates that financial performance is not a uniform determinant of ESG ratings. This pattern supports H2: firm size is a consistent positive correlate of ESG ratings, positive in ten of eleven sectors and significant in eight. In sectors where explanatory power is high but positive coefficients are scarce or absent - Information Technology in particular - the relationship is better characterised as one in which ownership and valuation structure constrain ESG ratings, rather than one in which financial performance drives them upward. A share of the remaining variance, in every sector, likely reflects non-financial factors such as corporate culture, regulatory environment, reputational risk, and strategic priorities [17, 21].

6. Limitations

The analysis is cross-sectional, using data as of the end of Q1 2025, and the identified associations should be interpreted as correlational rather than causal; a longitudinal design using dynamic panel data would be needed to establish the direction and stability of causality. ESG ratings are drawn from a single provider (LSEG), which introduces provider-specific measurement bias given the well-documented divergence across rating agencies. Each sector-level model is estimated on 68 firms, which, while adequate for the ten-predictor specification used, limits statistical power and warrants caution in generalising sector-specific coefficients.

7. Conclusion

This study finds that the relationship between corporate financial performance and ESG ratings is highly heterogeneous across GICS sectors, ranging from a non-significant model in Consumer Discretionary to $R^2 = 0.54$ in Information Technology and Healthcare. Company size is the most robust positive predictor of ESG ratings across sectors, while market valuation multiples and ownership concentration are consistently negatively associated with ESG ratings where significant. Applying a classification criterion - a statistically significant model with at least two positive, significant coefficients - only the Industrials sector combines high explanatory power with a genuinely positive, multivariable financial-performance channel; in Information Technology and Healthcare, comparable explanatory power is instead driven by negative associations with ownership concentration and market valuation. These findings demonstrate that the strength and direction of the CFP–ESG relationship cannot be generalised across sectors, and that sector context - particularly ownership structure and market valuation - is a first-order determinant of how financial performance and ESG ratings relate.

References

1. Ma Q. Exploring the multi-dimensional effects of ESG on corporate valuation: insights into investor expectations, risk mitigation, and long-term value creation. Adv Econ Manag Polit Sci. 2024;103:8–15.

2. Huang R, Meng J, Xiu S. A review of the role of ESG performance of listed companies on financial performance: theory, effect, influencing factors and path. J Stat Econ. 2024;1(3):7–15.

3. Spence M. Job market signaling. Q J Econ. 1973;87(3):355–374.

4. Connelly BL, Certo ST, Ireland RD, Reutzel CR. Signaling theory: a review and assessment. J Manag. 2011;37(1):39–67.

5. Hummel K, Schlick C. The relationship between sustainability performance and sustainability disclosure: reconciling voluntary disclosure theory and legitimacy theory. J Account Public Policy. 2016;35(5):455–476.

6. Jensen MC, Meckling WH. Theory of the firm: managerial behavior, agency costs and ownership structure. J Financ Econ. 1976;3(4):305–360.

7. Wang S. The respective relationship between environmental, social, governance and financial performance. Adv Econ Manag Polit Sci. 2024;115:107–111.

8. Danielson M, Hogan KM, Olson GT. Reconciling shareholder theory in the age of ESG. In: Karger E, Kostyuk A, editors. Corporate governance: an interdisciplinary outlook. Virtus Interpress; 2023. p. 115–116.

9. Friede G, Busch T, Bassen A. ESG and financial performance: aggregated evidence from more than 2000 empirical studies. J Sustain Finance Invest. 2015;5(4):210–233.

10. Whelan T, Atz U, Van Holt T, Clark C. ESG and financial performance: uncovering the relationship by aggregating evidence from 1,000 plus studies published between 2015–2020. New York: NYU Stern Center for Sustainable Business; Rockefeller Asset Management; 2021.

11. Gillan SL, Koch A, Starks LT. Firms and social responsibility: a review of ESG and CSR research in corporate finance. J Corp Finance. 2021;66:101889.

12. Halid S, Rahman RA, Mahmud R, Mansor N, Wahab RA. A literature review on ESG scores and their impact on firm performance. Int J Acad Res Account Finance Manag Sci. 2023;13(1):272–282.

13. Testa M, D'Amato A. Corporate environmental responsibility and financial performance: does bidirectional causality work? Empirical evidence from the manufacturing industry. Soc Responsib J. 2017;13(2):221–234.

14. Crespi F, Migliavacca M. The determinants of ESG rating in the financial industry: the same old story or a different tale? Sustainability. 2020;12(16):6398.

15. Hamdi K, Guenich H, Ben Saada M. Does corporate financial performance promote ESG? Evidence from US firms. Cogent Bus Manag. 2022;9(1).

16. Priyanto P, Suhandi NPM. Unraveling the link: relationship between firm value and ESG ratings. J Account Bus Educ. 2023;8(2):61–71.

17. Giese G, Shah D. MSCI ESG ratings in global equity markets: a long-term performance review. MSCI ESG Research LLC; 2024.

18. Breusch TS, Pagan AR. A simple test for heteroscedasticity and random coefficient variation. Econometrica. 1979;47(5):1287–1294.

19. Krishnan CNV, Yang J, Tan X. Do environmental, social, and governance (ESG) factors matter? Analyzing the relationships between firm characteristics and ESG scores. Businesses. 2024;4(4):566–581.

20. Giordino D, Sestino A, Zàmek D, Yahiaoui D. The impact of institutional ownership structure on corporate ESG performance: empirical evidence for the European capital market. Rev Manag Sci. 2025;20:537–578.

21. Wang R, Zhu W. How does ESG performance affect corporate financial performance? Sci J Econ Manag Res. 2024;6(7):54–61.

DEVELOPMENT OF APPROACHES TO THE MANAGEMENT OF THE NATIONAL ECONOMIC SYSTEM (USING THE EXAMPLE OF THE DIGITAL ECONOMY SECTOR)

Verigo Anastasiya
PhD (economics), Associate Professor,
Associate Professor of the Department of Banking Business and Financial Technologies,
Belarusian State University, Minsk, Belarus
DOI: 10.5281/zenodo.21837026

Abstract
The article analyzes the main macroeconomic indicators that characterize the effectiveness of the digital economy. The trends of these indicators are revealed. The relevance of the application of adaptive management of the national economic system is substantiated using the example of the digital economy sector. The main elements of the implementation of adaptive management of the national economic system are considered. The main tasks of implementing adaptive management are studied. The advantages of adaptive management of the national economic system in the context of digitalization are revealed.

Keywords: national economic system, management theory, systems theory, adaptive management; digital economy.

Introduction. In modern conditions of functioning of national economic systems, the development of approaches to their management is of particular importance. The following well-known scientists have made a great contribution to the study of economic management issues: V.F. Baynev, M. Weber, A.I. Korotkevich, M.M. Kovalev, E.Z. Maiminas, I.V. Novikova, S.Y. Solodovnikov, A.N. Folomiev, V.N. Shimov, E.G. Yudin, Yu.M. Yasinsky and others. However, the following issues have not been sufficiently studied: assessment of the non-linearity of the elements of the national economic system; assessment of the dynamic nature of the system and its individual elements; analysis of the relationships between a large number of indicators; assessment of the time period from the beginning of the management process to obtaining the planned result. The results presented in the article are based on modern advances in management theory, systems analysis, and adaptive management by scientists such as: A.G. Alexandrov [1], V.N. Antonov, A.M. Prishvin, V.A. Terekhov, A.E. Yanchevsky [2], S.V. Bugrov, R.A. Lisovoy, V.A. Zhmud, A.B. Kolker [3], A.A. Bobtsov, V.O. Nikiforov, A.A. Pyrkin [4], V.A. Besekersky, E.P. Popov [5], A.V. Voronin [6], I.Yu. Tyukin, V.A. Terekhov [7] and others. The development of approaches to the management of the national economic system includes: the development of mechanisms for mutual advanced multilevel adaptation; ensuring the effectiveness of the management process; the implementation of flexible adaptation of the national economic system to external and internal changes. To achieve these objectives, it is necessary to conduct a comprehensive analysis of economic indicators. These aspects determine the purpose and relevance of the article. The study is based on the example of the digital economy sector.

Results and discussion. Digitalization has an impact on all areas of activity, including economic activity. The development of digitalization makes it possible to apply new methods of identification, analysis and evaluation of empirical data. Modern approaches to management should take into account the following aspects: 1) the non-linearity of the elements of the national economic system; 2) the multiple connectivity and multiparametricity of indicators; 3) the temporal characteristics of management and the system's response to management. The practical implementation of these aspects is carried out with the help of management tools. It should be classified according to different criteria. One of these classification criteria is the sectors of the economy. To substantiate the relevance of developing approaches to managing the national economic system in the context of digitalization, consider the dynamics of the main socio-economic indicators of the digital economy ("ICT sector", "Content and Media Sector" [8]). Table 1 shows the dynamics of the number of digital economy organizations, their number on the payroll, and the average monthly salary of employees.

Table 1

Dynamics of the number of digital economy organizations, their number on the payroll, and employee salaries

Indicator	Period					
	2019	2020	2021	2022	2023	2024
Number of digital economy organizations, units	6 967	7 045	7 193	7 368	7 807	8 533
The list of employees of digital economy organizations, people	132 688	140 979	148 577	142 798	129 418	130 549
- to the previous year, %	108,1	106,2	105,4	96,1	90,6	100,9
- to the total number of employees on the list of organizations, %	3,5	3,8	4	4	3,6	3,7
Nominal accrued average monthly salary of employees of digital economy organizations, rubles	2 831,9	3 712,5	4 234,1	4 526,9	4 731,0	5 024,5
- to the average salary in the republic, %	259,1	295,9	293,3	277,2	246,9	219,5

Source: [8].

In accordance with the data presented in table 1, we can note a steady growth trend in the number of digital economy organizations, the amount of accrued average monthly wages for employees of organizations, as well as a significant excess of its size relative to the average salary in the republic as a whole. During the analyzed period, this excess was more than 200%. The real wages of employees of digital economy organizations also have a positive trend compared to the previous year.

Table 2 shows the growth rate of the number of organizations, their number of employees, and their salaries. During the analyzed period, there are differences in the growth rates of these indicators. The number of digital economy organizations is constantly increasing (from 101.12% to 109.3%). The growth rate of nominal and real wages has no stable trend. However, it always retains a positive value. The ratio of the nominal average monthly salary of employees of digital economy organizations to the average salary in the republic is gradually decreasing.

Table 2

Growth rate of the number of digital economy organizations, their list size, employee salaries, %

Indicator	Period				
	2020 / 2019	2021 / 2020	2022 / 2021	2023 / 2022	2024 / 2023
Number of digital economy organizations	101,12	102,10	102,43	105,96	109,30
The list of employees of digital economy organizations	106,25	105,39	96,11	90,63	100,87
Nominal accrued average monthly salary of employees of digital economy organizations	131,10	114,05	106,92	104,51	106,20

Source: compiled by the author based on [8].

Table 3 shows the dynamics of the total gross value added (GVA) of the digital economy and its share in various indicators. As can be seen from the table, the gross value added of the digital economy is constantly growing. At the same time, the GVA of the digital economy is decreasing in the total amount of GVA and in the gross domestic product of the country. Labor productivity, which is calculated according to the GVA (GVA per employee), is increasing. The absence of stable correlations between the amount of GVA and the number of employees of digital economy organizations, as well as between the amount of GVA and the indicator "the ratio of labor productivity according to GVA to the nominal salary of employees of digital economy organizations" has been revealed. Conclusion: there are other significant factors that influence the formation of these indicators.

Table 3

Dynamics of the total GVA of the digital economy and its share in various indicators

Indicator	Period					
	2019	2020	2021	2022	2023	2024
GVA of the digital economy:						
- at current prices, million rubles	9 364,7	11 640,1	14 000,6	13 329,4	13 011,6	15 140,1
- to the GVA on Economics, %	8	8,9	9	7,7	6,8	7
- to GDP, %	7	7,8	7,9	6,9	6	6,1
- compared to the previous year (in comparable prices, %)	112,3	109	109,2	97,5	94,5	105,1
GVA for 1 employee, rubles.	70576,8	82566,2	94231,3	93344,4	100539,3	115972,5

Source: [8].

As can be seen from Table 4, there were positive growth rates of the analyzed indicators in the three periods studied. The values of indicators equal to less than one hundred percent were associated with changes in logistics, changes in individual economic processes, and external factors.

Table 4

Growth rate of the total GVA of the digital economy and its share in various indicators, %

Indicator	Period				
	2020 / 2019	2021 / 2020	2022 / 2021	2023 / 2022	2024 / 2023
GVA of the digital economy:					
- at current prices	124,30	120,28	95,21	97,62	116,36
- to the GVA on Economics	111,25	101,12	85,56	88,31	102,94
- to GDP	111,43	101,28	87,34	86,96	101,67
GVA for 1 employee	116,99	114,13	99,06	107,71	115,35

Source: compiled by the author based on [8].

Let's consider the dynamics of the net profit of digital economy organizations and foreign investments that have entered digital economy organizations (Table 5).

Table 5

Dynamics of net profit of digital economy organizations and foreign investments that went to digital economy organizations

Indicator	Period					
	2019	2020	2021	2022	2023	2024
Net profit of digital economy organizations, million rubles, Including:	2 046,8	2 747,2	2 620,5	2 355,1	2 690,4	3 352,7
- The ICT sector	1 956,7	2 666,7	2 550,3	2 265,1	2 584,1	3 098,8
- the content and media sector	70,4	41,3	53,3	58,6	69,6	127,6
- digital commerce	19,7	39,2	17	31,4	36,8	126,4
Foreign investments received by digital economy organizations, million USD:	732,5	661	884,4	823,5	828,9	772,1
- to the total volume of foreign investments, %	7,3	7,6	10,2	11,8	10,7	11,2

Source: [8].

The amount of net profit is constantly increasing. The bulk of the net profit was generated in the information and communication technology sector. The foreign investments that have entered the organizations of the digital economy are approximately at the same level. The Republic of Belarus has created all the conditions (benefits, preferences, etc.) for the development of this sector. The increase in the share of foreign investments received by digital economy organizations in the total volume of foreign investments did not lead to a similar increase in the gross value added of the digital economy in the total amount of gross value added and in the gross domestic product. There is a question of increasing the efficiency of using investments. The considered indicators are related to the indicators presented in Tables 1-4. Current issues: how to find the strength of their relationship; how to calculate the level of dependence of indicator values on external and internal influences.

The growth rate of these indicators is shown in Table 6. In 2024 and 2023, there is a positive growth rate in terms of "net profit". However, according to the "foreign investment" indicator, the growth rate has no stable trends. In three periods, there was a decrease in the growth rate for this indicator.

Table 6

Growth rate of net profit of digital economy organizations and foreign investments received by digital economy organizations, percent

Indicator	Period				
	2020 / 2019	2021 / 2020	2022 / 2021	2023 / 2022	2024 / 2023
Net profit of digital economy organizations, Including:	134,22	95,39	89,87	114,24	124,62
- The ICT sector	136,29	95,64	88,82	114,08	119,92
- the content and media sector	58,66	129,06	109,94	118,77	183,33
- digital commerce	198,98	43,37	184,71	117,20	343,48
Foreign investments received by digital economy organizations	90,24	133,80	93,11	100,66	93,15

Source: compiled by the author based on [8].

Let's summarize the trends that were listed in tables 2-6: 1) change in 2024 compared to 2023: positive growth rate of gross value added and net profit; decrease in the growth rate of foreign investment; increase in labor productivity according to GVA; 2) change in 2023 compared to 2022: positive growth rate of net income profit; decrease in GVA at current prices; the amount of foreign investment has hardly changed; 3) change in 2021 compared to 2020: increase in GVA at current prices; increase in labor productivity according to GVA; decrease in net profit; The growth rate of foreign investment was 133.8%. The example confirms the presence of a complex influence of various groups of factors on the formation of final indicators. The strength of each factor's influence may vary depending on the presence or absence of other factors. The quality of the management process depends on the identification and comprehensive analysis of these factors. To improve the quality of management, it is necessary to improve the quality of methodological tools for assessing economic processes and economic phenomena.

An effective management system should: 1) to evaluate the coefficient of delay (delay in time) of the system's response to various types of internal and external influences; 2) to take into account the nonlinearity of the system elements, multi-connectivity and multiparametricity of parameters; 3) to take into account the function of time; 4) to ensure flexibility, efficiency, and stability of the system. This scientific and practical task can be solved within the framework of the implementation of adaptive management of the national economic system.

As the scientists correctly noted, "control in conditions of parametric uncertainty and when measuring ... inputs and outputs ... with a delay is certainly the most difficult task" [4, p. 8]. To solve the problem, the author of the article suggests distinguishing three adaptive control contours: the main contour; the disturbance control contour, and the adaptive contour (for more details, see [9]). These contours cover the following elements of the adaptive management system of the national economic system: management object; control action; executive mechanism; the reference (target) model of the national economic system; the analyzer of characteristics of the real model of the national economic system; the block of perturbation assessment (the analyzer of internal and external perturbations); the amplifier; the filter; the correcting methodical toolkit (corrector); the block of adaptation (adaptive impact (management)); the methodical toolkit for the analysis of various processes and phenomena [10]. The last element includes: an input signal analyzer; an output signal analyzer; and a control error analyzer (for more details, see [11]). All management contours should be applicable to assess the transitional characteristics of the national economic system. In the theory of systems, "a transient characteristic ... describes a transient process ... that occurs when ... an impact is applied" [5, p. 50]. This is the reaction of a dynamic system to an external influence applied to it. It is estimated from the moment of application of this effect to a certain steady-state value.

In the context of substantiation and development of methodological tools for the implementation of adaptive management of the national economic system, it is proposed to use a synthesis of three management principles: deviation management; disturbance management; the principle of adaptation. These principles have been developed in management theory.

Let's consider the main tasks that need to be solved in order to implement effective adaptive management of the national economic system. The first task is to identify external (targeted, stochastic, deterministic, random) influences on the system and determine the frequency of their fixation. The main characteristics of these influences are: 1) a large number of types of factors; 2) the presence of a lag link; 3) the uncertainty of the appearance of factors; 4) the difference in the nature of the factors, which causes differences in their mathematical description; 5) the synergistic effect of different factors. The second task is to increase the information content of the parameters (indicators) used to assess the state, efficiency, and sustainability of the national economic system. The main reasons for the low information content of the indicators are: errors in empirical data; sampling errors; poor-quality methodological tools; violation of the methodology for calculating indicators; errors in the identification of cause-effect relationships, etc. The third task is to reduce static and dynamic calculation errors.

The fourth task is to identify and choose the type of (negative or positive) feedback. It is determined by the following characteristics of the national economic system: 1) it is a multidimensional control system that has several inputs and outputs; 2) it includes continuous and discrete subsystems; 3) all types of signals (effects) are continuous functions of time. The fifth task is the mathematical description and implementation of the principle of "deviation control". The sixth task is to limit the use of types, methods, tools, and regulatory mechanisms. Limitations can be related to objective (limited resources, the initial state of the economy, etc.) and subjective (development priorities, international agreements, state interests in the global economic system, etc.) factors [12]). The seventh task is to assess the inertia of the national economic system. This problem manifests itself most strongly when the system needs to be over-regulated. The inertia of the system (or its individual elements) affects the speed of the "transition" from its current state to the "new (target)".

An important aspect of the adaptive management system is the identification of parameters (indicators) reflecting the signs of adaptation of the national economic system.: reducing the volatility of macroeconomic indicators; achieving the stability of the national economic system in rapidly changing conditions of its functioning; stabilizing systemically important economic activities; reducing the frequency of over-regulation of system parameters; the ability to reconfigure system parameters depending on the characteristics of the management object.; reduction of the oscillation range when changing the parameters of external influences.

Conclusion. The main advantages of adaptive management of the national economic system are:

changing the dynamic characteristics of the system; ensuring flexibility of management; increasing the speed of management; increasing the stability of the economic system; the ability to change the parameters of the control effect depending on changes in the characteristics of the management object; the availability of correction of system parameters; improving the efficiency of management decisions; the use of compensation mechanisms; reducing static and dynamic management errors.. Thus, adaptive management increases flexibility, ensures the alignment of changing properties and parameters of the national economic system with external and internal influences, with the main control contour.

References

1. Aleksandrov A.G. Optimal and adaptive systems. Moscow: Higher School, 1989. 263 p. [Published in Russian].

2. Antonov V.N., Prishvin A.M., Terekhov V.A., Yanchevsky A.E. Adaptive automatic control systems: textbook manual; edited by V.B. Yakovlev. Leningrad : Publishing House of the Leningr University, 1984. 204 p. [Published in Russian].

3. Bugrov S.V., Lisovoy R.A., Zhmud V.A., Kolker A.B. Adaptive control system using the stabilizing effect of deviation of the regulator coefficient // Scientific Bulletin of NSTU. 2010. No. 1(38). pp. 157-160. [Published in Russian].

4. Bobtsov A.A., Nikiforov V.O., Pyrkin A.A. Adaptive control of perturbed systems: textbook stipend. St. Petersburg: ITMO University, 2015. 126 p. [Published in Russian].

5. Besekersky V.A., Popov E.P. Theory of Automatic Management Systems. 4th ed., rev. and expanded. St. Petersburg: Professia Publishing House, 2003. 752 p. [Published in Russian].

6. Voronin A.V. Adaptive control systems: textbook manual; Tomsk Polytechnic University. Tomsk : Publishing House of Tomsk Polytechnic University, 2022. 138 p. [Published in Russian].

7. Tyukin I.Yu., Terekhov V.A., Adaptation in nonlinear dynamic systems (Series: Synergetics: from the past to the future). St. Petersburg: LKI, 2008. 384 p. [Published in Russian].

8. Information Society in the Republic of Belarus, 2025 : statistics. collection [Electronic resource] // National Statistical Committee of the Republic of Belarus. URL: https://www.belstat.gov.by/ofitsialnaya-statistika/publications/izdania/public_compilation/index_152032 / (date of access: 15.03.2026) [Published in Russian].

9. Verigo, A.V. Theoretical and methodological study of the problems of observation of the state of the national economic system and analysis of the national economic system // Journal of the Belarusian State University. Economics. 2025. No. 2. pp. 111–125.

10. Verigo A. Selected aspects of Adaptive Management of the National Economic System // Education and Science without Borders: Fundamental and Applied Research. 2026, № 23. pp. 40-45.

11. Verigo A. Selected Aspects of Modeling Adaptive Management of the National Economic System // XXI international scientific conference. Toronto. Canada. 09-10.04.2026. pp. 45-47.

12. Verigo A.V. Theoretical and methodological aspects of assessing the stability of the economic system of the state // Economics today : a collection of scientific articles / editors: S. Y. Solodovnikov (chief editors), V. F. Baynev, V. V. Bogatyreva [and others]. Minsk : BNTU, 2025. Issue. 22. Pp. 88-97.

STRATEGIC MANAGEMENT OF CULTURAL TOURISM AS A TOOL FOR SUSTAINABLE TOURISM DEVELOPMENT IN GEORGIA

Nino Orjonikidze,
Professor, Doctor of Economics
Gori State University
Head of Quality Assurance Service
ORCID: 0009-0007-6092-7587
Natia Zhozhuashvili
Associate Professor, Doctor of Economics
Gori State University
Head of the Bachelor's Program in Business Administration
ORCID: 0009-0008-4882-3467
DOI: 10.5281/zenodo.21837053

Abstract

Under the conditions of modern tourism development, cultural tourism is considered one of the most dynamic and sustainable forms of tourism, playing an important role in economic growth, the protection of cultural heritage, and the social and cultural development of local communities. The strategic management of cultural tourism has therefore become especially important, as it ensures the effective planning, management, and sustainable use of tourism resources, supports the diversification of tourism products, and balances heritage protection with economic benefit. Georgia, as a country with a long history, rich cultural traditions, and unique historical heritage, has significant potential for the development of cultural tourism. The application of modern strategic management approaches is therefore an important prerequisite for the sustainable development of the country's tourism industry and for improving its competitiveness in the international tourism market.

Keywords: Cultural tourism; Strategic management; Sustainable tourism; Cultural heritage; Georgia; Regional development.

Introduction

Tourism is one of the fastest-growing and most strategic sectors of the global economy in the twenty-first century. Over the past decades, changing tourist preferences have increased demand for products that offer not only leisure and recreation but also authentic cultural experiences. As a result, cultural tourism, which focuses on exploring heritage, historical monuments, architectural sites, traditions, festivals, and the lifestyle of local communities, has become one of the most important and rapidly developing segments of the international tourism market, contributing both to the growth of arrivals and to the preservation of cultural values and local economic well-being. Sustainable tourism is based on balancing three key dimensions: economic efficiency, social responsibility, and environmental protection, meeting the needs of present visitors and host communities while protecting cultural and natural resources for future generations. Strategic management plays a crucial role in this balance by ensuring that development is carefully planned, effectively managed, and aligned with sustainability principles.

Georgia possesses exceptional opportunities for cultural tourism thanks to its rich historical heritage, diverse traditions, unique architectural monuments, and valuable intangible cultural heritage. These resources create favourable conditions for strengthening the country's position in the international tourism market. However, achieving sustainable growth requires modern strategic management that supports effective resource management, innovation, stakeholder cooperation, and long-term planning, thereby improving competitiveness, diversifying tourism products, protecting cultural heritage, increasing the economic benefits generated by tourism, and strengthening cooperation among public institutions, private businesses, local communities, and cultural organisations, which is essential for sustainable destination management. This study aims to examine the role of strategic management in the sustainable development of cultural tourism in Georgia: how it contributes to the effective use of heritage resources, strengthens destination competitiveness, and supports sustainable economic and tourism development, while identifying the main opportunities and challenges in implementing modern strategic management approaches within the sector.

Research methods: research-based, theoretical, and empirical methods are used in the literature review, comparative analysis, and statistical data processing, which provides an in-depth study of the issue.

Basic text

Georgia's Potential for the Development of Cultural Tourism

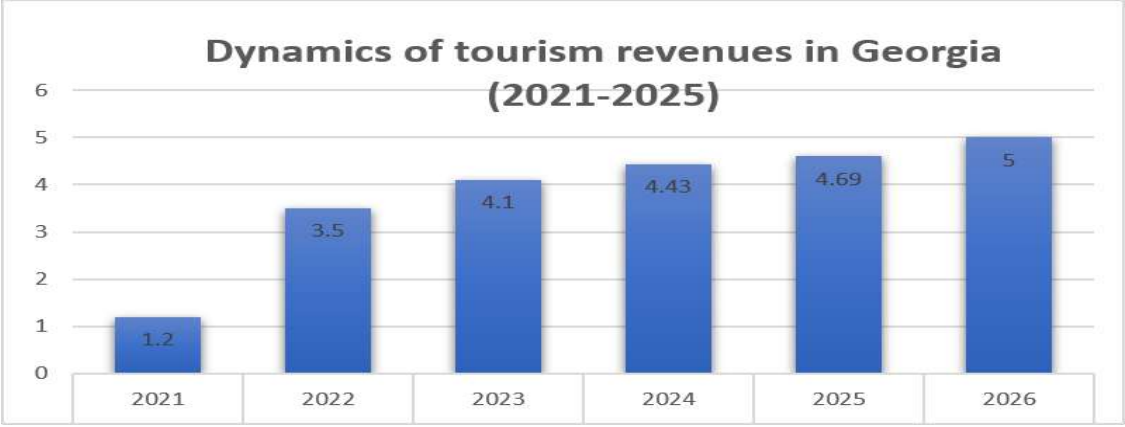
Georgia's competitive advantage rests on its rich cultural heritage, centuries-old history, religious diversity, ethnographic traditions, and unique cultural landscapes. Historical monuments, **UNESCO World Heritage Sites,** traditional culture, and intangible cultural heritage together provide a strong foundation for sustainable cultural tourism. According to **the UNESCO World Heritage Centre**, Georgia currently has four properties on the World Heritage List[2]: the **Historical**

[2] UNESCO World Heritage Centre, Georgia – Properties Inscribed on the World Heritage List (2026)

Monuments of Mtskheta (including the Svetitskhoveli Cathedral and the Jvari Monastery- 1994), the **Gelati Monastery, Upper Svaneti (1994), and the Colchic Rainforests and Wetlands**, added in 2021 as a natural heritage site[3]. These internationally recognised sites are valuable assets for Georgia's long-term tourism strategy, and their preservation and effective management are essential for sustainable development and protecting cultural identity for future generations. The Georgian tourism sector recorded strong growth in 2025. According to the National Statistics Office of Georgia, the country welcomed 7.8 million international non-resident travellers, with 6.9 million international visits and 5.8 million individual international visitors; 5.5 million of these visits were classified as tourism visits. [4]This growth reflects the international recognition of Georgia's cultural attractions and creates opportunities for regional development, investment, and employment, but also increases the responsibility of institutions to ensure that development remains sustainable through effective planning and coordinated destination management.

Economic Contribution of Tourism and Recent Development Trends in Georgia

Before the COVID-19 pandemic, tourism was one of Georgia's fastest-growing industries: in 2019, international tourism generated USD 3.3 billion, approximately 8.1% of national GDP.[5] The pandemic caused a severe decline, with receipts falling to USD 541.7 million in 2020, one of the lowest levels in recent decades. [6]From 2022 onward, the sector recovered steadily, largely regaining pre-pandemic performance by 2023. According to Geostat, the direct gross value added generated by tourism reached approximately GEL 5.3 billion in 2024 (compared with GEL 4.9 billion in 2023), accounting for nearly 7.3% of GDP. International tourism receipts reached approximately USD 4.4 billion in 2024, a 7.3% increase year-on-year. [7]



These positive results indicate that Georgia has successfully restored its position in the international tourism market and continues to strengthen its competitiveness. This trend continued in 2025, Georgia's highest year on record: according to the National Bank of Georgia, receipts exceeded USD 4.69 billion (about 6% growth), total visitor expenditure reached approximately GEL 15 billion (up 5.1%), and average expenditure per visit reached GEL 2,187.3. This value is distributed mainly across transport (43.5%), accommodation (32.3%), food and beverage (21.1%), and travel agencies and tour operators (3.1%), confirming tourism as a main pillar of the Georgian economy that stimulates investment, supports SMEs, creates employment, and promotes balanced regional development. From a cultural tourism perspective, these achievements underline the importance of sustainable planning, heritage investment, improved services, and stronger stakeholder cooperation to increase economic benefit further while protecting cultural resources long-term.[8]

Modern Strategic Management Approaches to Cultural Tourism

Amid globalization, digital transformation, and rapidly changing tourism markets, cultural tourism development requires modern strategic management approaches focused on the efficient use of cultural resources, improving destination competitiveness, encouraging innovation, and ensuring sustainable tourism development. Sustainability-Oriented Management has become a fundamental principle of tourism management.[9] It aims to achieve a balance between economic growth, social well-being, and environmental protection, ensuring the preservation of cultural heritage, supporting local communities, and promoting responsible use of resources, without damaging cultural values or reducing the authenticity of historical and cultural sites. For Georgia, this is especially important given the close connection between national identity and its historical monuments, traditional architecture, religious heritage, wine culture, and intangible traditions, the preservation of which is essential not only for tourism but for protecting the nation's cultural identity.

Stakeholder Management recognises that the success of cultural tourism depends on effective cooperation among government institutions, local authorities,

[3] UNESCO World Heritage Centre, Colchic Rainforests and Wetlands (2021)
[4] National Statistics Office of Georgia (Geostat), Inbound Tourism Statistics (2025)
[5] World Bank, Georgia: Tourism Trends Analysis and Recommendations (2024)
[6] National Bank of Georgia, International Travel Receipts: Annual Data (2025)
[7] National Statistics Office of Georgia (Geostat), Tourism Satellite Accounts 1–4 (2025)
[8] World Bank, Georgia: Tourism Trends Analysis and Recommendations (2024)
[9] UN Tourism, Sustainable Development (2023)

tourism businesses, heritage organisations, educational institutions, non-governmental organisations, and local communities. Modern strategic management emphasises partnership throughout planning and implementation, which improves decision-making, increases transparency, strengthens public participation, and reduces conflicts of interest. This cooperation has become increasingly important in Georgia as cultural tourism projects and regional development initiatives grow, improving destination management and the quality of tourism services.

Integrated Destination Management (IDM) holds that a destination should be managed not as a collection of separate attractions but as an integrated system combining cultural heritage, tourism services, transport infrastructure, accommodation, marketing, environmental protection, and visitor management. For Georgia, this approach is particularly relevant for developing regional tourism products and cultural routes connecting historical cities, museums, monasteries, archaeological sites, and traditional villages, encouraging visitors beyond Tbilisi or Batumi and distributing tourism income more equally among regions, expanding employment and making regional economies more sustainable.[10] Georgia's strengths, including its rich cultural heritage, UNESCO World Heritage Sites, ancient wine-making traditions, historical cities, religious diversity, and unique ethnographic culture, create a strong competitive advantage in the international market. However, unevenly developed regional infrastructure, the need for improved international promotion of cultural attractions, and limited use of modern digital technologies remain challenges requiring long-term strategic planning, increased investment, and stronger cooperation among stakeholders.

Digital Transformation and Strategic Marketing in Cultural Tourism

Digital transformation has become one of the most influential factors in the development of modern cultural tourism, changing how destinations are managed, promoted, and experienced. Artificial Intelligence enables tourism organisations to analyse visitor behaviour, predict tourism demand, personalise services, and improve communication with visitors, while also helping decision-makers process large amounts of tourism data to develop more effective strategies. Virtual Reality allows visitors to experience historical monuments, museums, and archaeological sites through immersive digital environments, particularly valuable for people who cannot travel or who wish to explore destinations beforehand, while also reducing physical pressure on sensitive heritage sites. Augmented Reality enhances onsite visits by combining digital information with the real environment, with mobile applications providing historical information, interactive maps, multilingual guidance, and visual reconstructions of historical buildings. Data analytics further enables destination management organisations to monitor visitor flows, identify tourism trends, evaluate visitor satisfaction, and allocate resources more efficiently. Although Georgia has made progress in digital tourism, implementation of these technologies within the cultural tourism sector remains at an early stage, and greater investment in digital infrastructure and innovation would strengthen international visibility and competitiveness.

Strategic Marketing and Destination Branding are equally essential in today's competitive tourism industry, where destinations must create a strong, recognisable brand reflecting their unique cultural identity to attract international visitors, increase revenues, and strengthen global image. Strategic marketing promotes a destination's unique characteristics, including historical heritage, traditions, architecture, gastronomy, festivals, and local lifestyle, combining traditional promotional activities with digital communication channels and social media to reach broader audiences. For Georgia, branding should focus on its 8,000-year-old wine-making tradition, recognised by UNESCO as Intangible Cultural Heritage, its World Heritage Sites, medieval churches and monasteries, historical cities, traditional cuisine, polyphonic singing, folk dances, and rich ethnographic diversity, resources that together create a unique tourism identity differentiating Georgia from competing destinations, increasing international awareness, visitor spending, longer stays, repeat visits, and promoting lesser-known destinations alongside the country's major tourist centres.

Conclusion

Cultural tourism is one of the most important and promising sectors of modern tourism, contributing to economic growth, heritage preservation, community empowerment, and sustainable development goals. Countries with rich cultural resources have greater opportunities to strengthen their global position through effective strategic management. This study demonstrates that Georgia possesses considerable potential for sustainable cultural tourism development, grounded in its historical heritage, World Heritage Sites, unique traditions, and wine-making culture. This potential depends on the effective implementation of modern strategic approaches: sustainability-oriented management, stakeholder cooperation, integrated destination management, digital transformation, and strategic marketing, which together support the efficient use of cultural resources while ensuring their long-term preservation. Official statistics confirm tourism's growing economic importance, with rising visitor numbers, revenues, and GDP contribution creating favourable conditions for further investment. Nonetheless, uneven regional infrastructure, limited use of advanced digital technologies, and the need for stronger international promotion continue to affect long-term competitiveness, requiring stronger cooperation between public institutions, private businesses, local communities, and heritage organisations. The successful implementation of modern strategic management will strengthen the sustainable development of cultural tourism in Georgia, improving competitiveness, supporting heritage preservation, encouraging balanced regional development, and increasing long-term economic benefit. Future tourism policies should continue to focus on sustainable resource management, innovation, digital transformation, and

[10] OECD, OECD Tourism Trends and Policies (2024)

stakeholder collaboration, reinforcing Georgia's position as an internationally recognised cultural tourism destination while protecting its cultural identity for future generations. The findings of this study may serve as a useful reference for policymakers, destination management organisations, tourism businesses, and researchers involved in developing sustainable cultural tourism, supporting the formulation of policies that promote heritage conservation, regional development, and long-term competitiveness in Georgia's tourism sector.

References

1. National Bank of Georgia. (2026). International travel receipts: Annual data 2025. https://nbg.gov.ge/en/statistics/statistics-data

2. OECD. (2024). OECD tourism trends and policies 2024. OECD Publishing. https://www.oecd.org/en/publications/oecd-tourism-trends-and-policies-2024_80885d8b-en.html

3. National Statistics Office of Georgia (Geostat). (2025). Inbound tourism statistics 2025. https://www.geostat.ge

4. National Statistics Office of Georgia (Geostat). (2025). Tourism satellite accounts 1–4, 2024 [Data set]. https://www.geostat.ge/en/modules/categories/720/tourism-satellite-accounts

5. UNESCO World Heritage Centre. (2021). Colchic rainforests and wetlands. https://whc.unesco.org/en/list/1616

6. UNESCO World Heritage Centre. (n.d.). Georgia – Properties inscribed on the World Heritage List. Retrieved June 10, 2026, from https://whc.unesco.org/en/statesparties/ge

7. UN Tourism. (n.d.). Digital transformation. https://www.unwto.org/digital-transformation

8. World Bank. (2024). Georgia: Tourism trends analysis and recommendations. World Bank Group. https://documents1.worldbank.org/curated/en/099060424183542556/pdf/P5016461c0c9e502818eb419dba3272441a.pdf

9. World Bank. (2024). Georgia: Tourism trends analysis and recommendations. World Bank. http://hdl.handle.net/10986/41723

MATHEMATICAL SCIENCES

TOWARD GENERAL CLASSIFICATIONS OF *K*-GEODETIC GRAPHS: STRUCTURAL FOUNDATIONS, ALGORITHMIC CHALLENGES, AND EMERGING RESEARCH DIRECTIONS

Frasser C.E.
Ph. D. in Engineering Sciences, Odessa National Polytechnic University, Ukraine
DOI: 10.5281/zenodo.21837097

Abstract

The general classifications of *k*-geodetic graphs, for each of their families $k = 1, 2, 3$, remain notoriously difficult open problems in discrete mathematics. A *k*-geodetic graph *G* is a connected one in which every pair of vertices is joined by at most *k* shortest paths, where *G* is geodetic if $k = 1$, bigeodetic if $k = 2$, and trigeodetic if $k = 3$, making these structures fundamental to graph theory, combinatorial optimization, and network design. Despite decades of research primarily dealing with geodetic graphs, and more recently, dealing with bigeodetic and trigeodetic ones, no comprehensive structural characterizations have been established. This paper reviews the principal mathematical barriers that have prevented complete classifications and discusses recent structural approaches based on embedded even graphs, bigeodetic graphs, and combinatorial design theory. Particular attention is given to the algorithmic challenges associated with generating and enumerating *k*-geodetic graphs, where exhaustive computational methods become NP-hard. The paper further explores the use of Balanced Incomplete Block Designs (BIBDs) as algebraic seeds for constructing higher-order *k*-geodetic structures while substantially reducing computational search complexity. Finally, several future research directions are proposed, including connections between *k*-geodetic graph theory and number theory, and applications in communication network topology, quantum routing architectures, graph neural networks, computational complexity, and exploratory mathematical models connecting discrete graph spaces with continuous physical systems.

Keywords: *K*-Geodetic graphs, *k*-geodetic graph classification, shortest paths, combinatorial design theory, BIBDs, graph enumeration, NP-hard problems, graph algorithms, discrete mathematics.

Introduction

The classification of mathematical structures has historically played a central role in the advancement of mathematics. Just as finite groups, finite geometries, and algebraic structures have been systematically organized through structural theorems, graph theory continues to seek comparable classifications for increasingly complex graph families.

Among these challenges, the classification of geodetic graphs remains unresolved. Originally formulated by Oystein Ore in 1962, the problem seeks a complete characterization of all connected graphs in which every pair of vertices is connected by exactly one shortest path. Although many important subclasses have been identified—including trees, block graphs, and various distance-hereditary structures—a universal classification has remained elusive for more than six decades.

The difficulty arises because geodeticity is an inherently global property. Small local modifications, including the insertion of a single edge, may generate additional shortest paths and destroy the geodetic property. Consequently, conventional graph construction methods are poorly suited for systematic classification.

This paper examines two principal mathematical barriers that have limited progress toward a general classification and discusses several structural approaches that may provide a foundation for future advances.

1. The Open Classification Problem

The central objective is to determine a complete structural characterization of all geodetic graphs.

Unlike many graph classes defined by forbidden subgraphs or hereditary properties, geodetic graphs depend on global shortest-path uniqueness. This characteristic prevents simple recursive constructions and complicates both theoretical analysis and computational generation.

Current research suggests that the classification problem consists of three interconnected mathematical obstacles.

a. Structural Description Deficit

Perhaps the greatest obstacle is the absence of a fundamental structural description [1, 3].

At present, there exists no accepted set of primitive building blocks from which all geodetic graphs may be generated. While numerous local properties have been established, these results have not converged toward a universal structural theory.

One proposed direction [1] introduces embedded even graphs together with bigeodetic graphs as elementary structural components. Since bigeodetic graphs permit at most two shortest paths between non-adjacent vertices, they may represent intermediate structures from which purely geodetic graphs can be understood through controlled restrictions on shortest-path multiplicity.

Developing such a structural framework may ultimately provide the missing foundation required for a general classification theorem.

b. Fragmentation Through Subclass Analysis

Historically, researchers have concentrated on particular subclasses of geodetic graphs rather than the complete family.

Although valuable results have been obtained for trees, block graphs, cycles, complete graphs, Moore graphs and other specialized structures [3], these clas-

sifications remain largely isolated. Properties established within one family rarely generalize naturally to others.

Consequently, the literature has developed as a collection of disconnected local classifications rather than a unified mathematical theory. Overcoming this fragmentation requires identifying invariant structural principles that extend across all subclasses.

c. Construction and Enumeration Challenges

Classification requires the ability to generate, enumerate, and verify candidate graphs.

Unfortunately, geodetic graphs are exceptionally sensitive to structural perturbations. Traditional graph operations frequently introduce additional shortest paths, immediately violating geodeticity.

This interdependence creates a circular problem:

- classification requires enumeration,
- enumeration requires graph construction,
- graph construction requires structural characterization,
- yet structural characterization itself depends upon classification.

Breaking this cycle remains one of the principal objectives of current research.

The construction and enumeration of geodetic graphs homeomorphic to a given geodetic one using their geodetic system of Diophantine equations has been described in [5] establishing an unexpected new connection between graph theory and number theory through the use of combinatorial theory.

2. Computational Enumeration of *K*-Geodetic Graphs

From the computational perspective, enumerating *k*-geodetic graphs constitutes an NP-hard problem.

Traditional algorithms follow a generate-and-test paradigm:

1. Generate candidate non-isomorphic graphs.
2. Compute all-pairs shortest paths.
3. Count shortest-path multiplicities.
4. Reject graphs violating the *k*-geodeticity condition.

Although conceptually straightforward, exhaustive search rapidly becomes computationally infeasible because the number of possible graphs grows exponentially with the number of vertices.

Modern approaches therefore employ:

- constraint satisfaction methods,
- SAT solving,
- look-ahead pruning,
- cycle auditing,
- adjacency matrix exponentiation,
- bit-parallel shortest-path verification.

These techniques substantially reduce computational overhead while preserving exact verification.

BIBDs as Algebraic Seeds for Graph Construction

One promising research direction involves replacing blind graph generation with algebraically guided construction using Balanced Incomplete Block Designs (BIBDs) [2].

Rather than exploring the enormous search space of arbitrary graphs, BIBDs provide highly constrained incidence structures satisfying predetermined combinatorial properties.

When $\lambda=1$, the resulting incidence structure naturally limits redundant shortest paths and some of the generated graphs avoid undesirable four-cycles that commonly destroy geodeticity.

For higher-order *k*-geodetic graphs, increasing λ permits controlled path multiplicity while preserving much of the desirable combinatorial structure.

This strategy effectively converts graph generation from an unconstrained combinatorial search into an algebraically guided construction process.

Emerging Research Directions

The mathematical framework developed for *k*-geodetic graphs has potential applications extending beyond classical graph theory [4].

Network Topology Optimization

Unique shortest-path structures naturally support routing protocols requiring deterministic communication. Future work may investigate scalable implementations for cloud computing, distributed databases, and next-generation communication networks.

Quantum Computing

Quantum processors impose severe topological constraints on qubit interactions. *K*-geodetic routing structures may provide efficient communication architectures that minimize routing ambiguity while reducing gate overhead.

Algorithmic Complexity

The development of faster verification algorithms for *k*-geodetic constraints remains an important theoretical computer science problem. Integrating structural theorems with SAT solvers, graph isomorphism algorithms, and matrix-based verification techniques may significantly improve computational efficiency.

Graph Neural Networks

Many modern AI systems rely on graph representations. Structural enumeration techniques developed for *k*-geodetic graphs may inspire more efficient message-passing architectures and sparse graph embeddings.

Mathematical Physics

An intriguing long-term research direction concerns the relationship between discrete graph spaces and continuous physical models. Although currently a theoretical framework, investigating whether *k*-geodetic structures provide useful mathematical analogs for wave-particle duality, discrete spacetime, or relativistic geometry represents an interdisciplinary avenue worthy of future investigation rather than an established application. What we mean is that *k*-geodetic structures might help explain fundamental physics mysteries. Here is a detail breakdown translated into universal concepts.

1. The Core Premise: Discrete vs. Continuous

There are two different ways of modeling reality:

- **Discrete Graph Spaces (Mathematics):** A network made of isolated, distinct points (nodes) connected by lines (edges). Think of a digital pixel grid or a social network map.
- **Continuous Physical Models (Physics):** The traditional view of physics where space and time are

smooth, flowing, and infinitely divisible. Think of a smooth ramp or a flowing river.

This is the main question: *Can we use the rules of distinct networks to explain our smooth, physical universe?*

2. The Tool: *K*-Geodetic Structures

How to bridge these two worlds using *k*-geodetic structures.

- In standard geometry, a "geodesic" is the shortest path between two points (like a straight line on a flat map or a flight path on a globe).
- In graph theory, a graph is *k*-geodetic if there are at most *k* distinct shortest paths between any two points.
- We want to see if restricting the number of shortest paths *k* in a network creates mathematical patterns that mimic real-world physics.

3. The Three Physical Analogs

These network structures might serve as "analogs" for three major concepts in physics:

- **Wave-Particle Duality:** In quantum mechanics, light and matter act like both localized particles and spread-out waves. If a network allows exactly *k* pathways for information to travel, the way these paths overlap might naturally mimic how quantum waves interfere with each other, while still originating from distinct "particle-like" points.
- **Discrete Spacetime:** Standard physics treats space and time as a smooth fabric. However, quantum gravity theories suggest that at the smallest possible scale (the Planck scale), spacetime might actually be made of tiny, indivisible "chunks" or atoms of space. A graph space is naturally discrete, making it a candidate to model this atomic structure of reality.
- **Relativistic Geometry:** Einstein's theory of general relativity states that gravity is the bending of smooth spacetime, which dictates how objects move. In a network, you can simulate "bending" by changing how points are connected. Investigating this would mean checking if the shortest paths (geodesics) in a network behave like the paths of objects moving through gravitational fields.

Concluding Remarks

More than sixty years after Ore introduced the classification problem of geodetic graphs, a complete theory of *k*-geodetic graphs remains unavailable. The principal obstacles continue to be the absence of a universal structural description, the fragmentation of existing subclass results, and the computational complexity of graph generation and enumeration.

Recent research suggests that progress may require a shift away from exhaustive graph construction toward structurally guided methods grounded in combinatorial design theory. In particular, BIBD-based graph generation offers a promising framework for reducing search complexity while preserving essential *k*-geodetic properties.

Beyond the classification problems themselves, these developments have the potential to influence algorithm design, network optimization, quantum information routing, and computational graph theory. Continued integration of structural mathematics with modern computational methods may ultimately provide the breakthrough needed to resolve the *k*-geodetic graph conjecture and establish a comprehensive classification of *k*-geodetic graphs for each of their families $k = 1, 2, 3$.

References

1. C. E. Frasser, A Characterization of Geodetic Graphs in Terms of their Embedded Even Graphs, German International Journal of Modern Science 125 (2026) pp. 38-42.

2. C. E. Frasser, Block Designs and K-Geodetic Graphs: A Survey, Journal of Science. Lyon 62 (2025) pp. 20-24.

3. C. E. Frasser, The Open Problem of Finding a General Classification of Geodetic Graphs, German International Journal of Modern Science 36 (2022) pp. 7-9.

4. C. E. Frasser, Topological Analysis and Synthesis of Structures Related to Certain Classes of K-Geodetic Computer Networks, German International Journal of Modern Science 85 (2024) pp. 29-36.

5. C. E. Frasser, G. N. Vostrov, Geodetic Graphs Homeomorphic to a Given Geodetic Graph, Int. J. Graph Theory App. 12 (2020) pp. 13-44.

MEDICAL SCIENCES

THE WELLNESS CONCEPT IN CONTEMPORARY SOCIETY: CULTURAL AND HEALTH PERSPECTIVES

Mariana Angelcheva
*Doctor, Assoc. Prof, Ph.*D. Faculty of public health, health care and Tourism
National Sports Academy "Vassil Levski", Sofia, Bulgaria
ORCID ID: 0000-0002-9697-6088
DOI: 10.5281/zenodo.21837137

Abstract

The wellness concept has developed into an interdisciplinary framework encompassing health promotion, disease prevention, recreation, and sustainable lifestyle practices. This study examines the healthcare and cultural dimensions of wellness and its contribution to healthy lifestyles and professional competency development within the wellness industry. A multidisciplinary methodology was employed, integrating literature analysis, theoretical modeling, cognitive assessment, and expert evaluation. The findings demonstrate that contemporary wellness extends beyond recreational services by incorporating evidence-based health promotion, balanced nutrition, physical activity, stress management, and natural therapeutic approaches into comprehensive programs. Despite the rapid expansion of the global wellness economy, a shortage of qualified professionals persists. Bulgaria addresses this challenge through accredited higher education programs, supporting workforce development and reinforcing wellness as an integrated model for sustainable public health, education, and tourism.

Keywords*:* wellness concept; health promotion; healthcare; wellness tourism; interdisciplinary education.

Introduction

The contemporary wellness sector, whether considered as a recreation destination, a niche tourism market, or a health-oriented lifestyle, primarily targets individuals leading dynamic and demanding lives who require effective recovery and comprehensive wellness programs (3, 13, 22). Modern wellness consumers seek deep relaxation, physical recovery, and re-energization through evidence-based therapies founded on natural products, balanced nutrition, and regular physical activity, thereby promoting a sustainable healthy lifestyle (1, 5, 14). The number of holidays involving travel to wellness destinations offering comprehensive health packages increased substantially during the period 2017–2020. However, the shortage of qualified personnel continues to represent a major global challenge (15). According to data published by the Global Wellness Institute (17), the worldwide deficit of professionals possessing specialized knowledge and competencies in wellness tourism is estimated at approximately 180,000 employees. The same report emphasizes the urgent need to develop specialized educational and training programs at all educational levels, ranging from operational staff to senior management (16). Globally, the recreation and niche tourism industries serve more than four billion people annually (23). They generating revenues exceeding €300 billion and positioning the wellness economy among the fastest-growing sectors worldwide (2, 10, 15, 21). Nevertheless, comprehensive statistical data regarding the economic performance of the wellness industry in the Balkan region remain unavailable (9, 11, 18, 20). In response to the increasing demand for qualified professionals, Bulgaria has successfully accredited five higher education programs dedicated to wellness management and related disciplines during the past seven years, including Bachelor's, Master's, and Doctoral degree programs within the professional fields of Sport (7.6) and Health Care (7.5) at the National Sports Academy "Vasil Levski" (4, 6, 7, 8).

Methods

To examine the cultural and healthcare dimensions of the wellness concept, a multidisciplinary methodological framework was employed, including: analysis of findings from previous scientific studies conducted by the authors and critical review of reports and policy documents published by international organizations; theoretical modeling using heuristic, prognostic, normative, heuristic-programmatic, and pragmatic approaches; transformation of subjective evaluations into structured cognitive concepts and measurable constructs; systematization, classification, and ranking of expert assessments to establish hierarchical relationships and identify the principal dimensions of the wellness concept.

The schematic and graphical data presented in this study provide a comprehensive overview of the current state of the global wellness market and offer real-time insights into the development of wellness culture, as well as examples of best practices within the recreation industry and niche tourism. Understanding wellness culture and achieving higher levels of individual and societal well-being enable meaningful comparisons at international, continental, regional, and national levels. At the same time, the wellness concept continues to expand beyond the individual perspective by incorporating broader dimensions related to community development, governmental responsibility, and national health policy, thereby reinforcing its role as an interdisciplinary framework for health promotion, sustainable development, and quality of life.

Results

Assessing wellness status as the cumulative achievement of a balanced and desired state of harmony is a complex undertaking. As illustrated in the concep-

tual framework presented below, wellness encompasses a broad range of interrelated indicators, the majority of which are inherently subjective. Consequently, wellness is difficult to objectify, quantify, and interpret consistently over time. In the present study, wellness status is analysed through the following dimensions: living and experiencing life to its fullest potential; achieving an optimal level of individual health; attaining balance across the principal wellness domains, including emotional, intellectual, spiritual, social (interpersonal), environmental (planetary), cultural, and financial health; achieving professional balance and harmony. This multidimensional model combines subjective perceptions of life satisfaction with objective indicators of physical health and other health-related dimensions to evaluate overall professional and personal well-being. However, because each component changes dynamically continuously interacts with the others, comprehensive assessment remains challenging and, to some extent, conditional. Contemporary society increasingly recognises wellness as a primary health objective, frequently equating it with optimal physical health (Fig. 1).

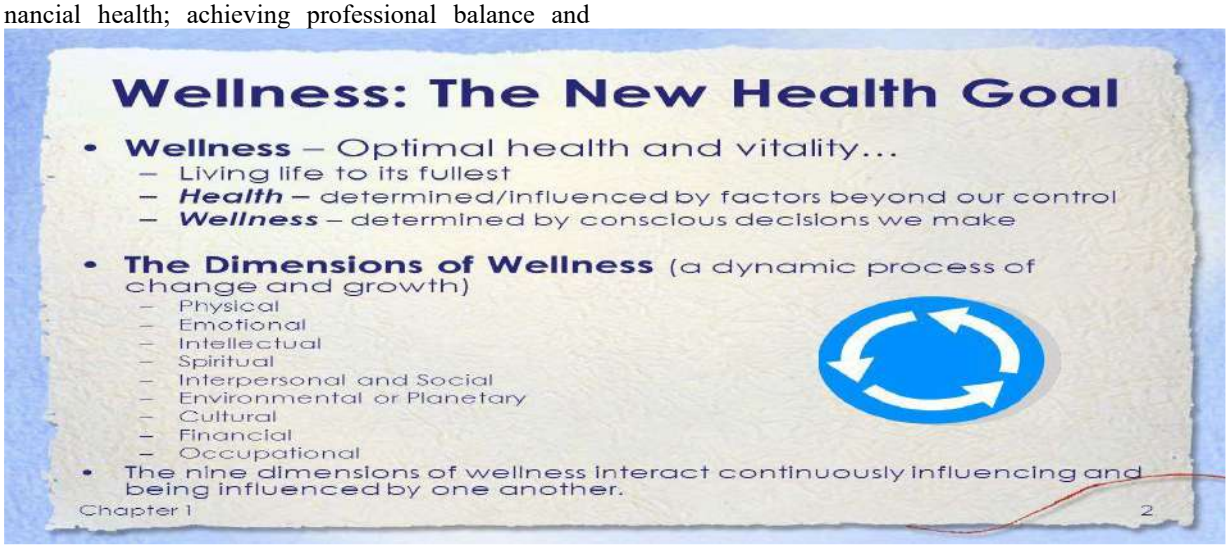

Wellness: The New Health Goal
• Wellness – Optimal health and vitality...
– Living life to its fullest
– Health – determined/influenced by factors beyond our control
– Wellness – determined by conscious decisions we make
• The Dimensions of Wellness (a dynamic process of change and growth)
– Physical
– Emotional
– Intellectual
– Spiritual
– Interpersonal and Social
– Environmental or Planetary
– Cultural
– Financial
– Occupational
• The nine dimensions of wellness interact continuously influencing and being influenced by one another.
Chapter 1
2

Figure 1. *Hierarchical Structure and Scope of Wellness Culture Indicators*

This widespread perception largely stems from the common assumption that wellness is synonymous with achieving and maintaining physical health and balance. However, this interpretation oversimplifies the concept and often confuses wellness with fitness. Fitness is generally defined as a state of physical preparedness achieved through proper nutrition, regular physical activity, sport participation, and adequate recovery. In contrast, wellness is a substantially broader concept encompassing multiple dimensions of health and quality of life that extend beyond physical fitness alone. The present study seeks to refine and expand the conceptual understanding of wellness by pursuing three primary objectives: To emphasize the cultural dimensions of health by examining the concepts of medical culture and health culture as essential components of contemporary health promotion; To define wellness culture as the newest dimension of health culture and as a contemporary standard for a health-promoting lifestyle; To highlight the growing relevance of the modern paradigm that "health is the new religion" which reflects the increasing social significance of health promotion concepts, preventive healthcare strategies, and wellness-oriented lifestyles (24). From a cultural perspective, the concept of culture refers to those meaningful aspects of human existence that are not products of nature but are created, developed, and transmitted through human activity. Culture may therefore be understood as:

1. an individual achievement expressed through work, creativity, values, and behavior; and
2. a collective heritage inherited from previous generations, continuously adapted and enriched through education, knowledge, self-development, and social practice.

Accordingly, culture may be defined as the totality of human-created systems, values, practices, and artifacts that complement the natural environment and are manifested through learned patterns of behavior, knowledge acquisition, self-awareness, education, and the symbolic expressions of society (24). Within this framework, wellness culture represents an interdisciplinary construct integrating health knowledge, behavioral practices, cultural values, and lifestyle choices that collectively contribute to individual well-being and sustainable health promotion. Health culture, including its medical dimension, is expressed through human activities that promote self-awareness, self-development, and the acquisition of health-related knowledge, attitudes, and behaviors aimed at maintaining and improving health. Consistent with the World Health Organization's definition of health as a state of complete physical, mental, and social well-being, health culture encompasses a wide range of preventive and health-promoting practices. Historically, the greatest emphasis has been placed on physical health, which is perceived both as a fundamental personal value when preserved and as a primary objective when compromised. The rapid development of fitness culture illustrates the evolution of a population-based approach to physical health promotion. More recently, this concept has expanded into wellness culture, which adopts a broader perspective by integrating multiple dimensions of individual well-being (Fig. 2).

Figure 2. *Architecture of personal health care for achieving a wellness-oriented lifestyle.*

This development raises an important question: *Which cultural phenomena provide the greatest functional benefits for human health?* Health-promoting practices that are readily accessible, require minimal resources, and can be incorporated into everyday life are generally the most sustainable. From a cultural perspective, human adaptation to changing environmental, social, and technological conditions may be regarded as an adaptive health-cultural syndrome, in which every process of medical cultural development contributes to the formation of new health behaviors, norms, and practices that facilitate healthy living and successful adaptation. Conversely, cultural patterns that restrict or hinder adaptation may adversely affect individual health and well-being. Among the various health-promoting strategies, regular physical activity remains the most widely adopted because of its well-established effectiveness, accessibility, and long-standing role in preventive healthcare. These characteristics have contributed to the global expansion of fitness as a health-promoting practice. Contemporary society, however, increasingly seeks more comprehensive health objectives that extend beyond physical fitness toward a higher quality of life, sustainable personal development, and long-term well-being. Consequently, wellness culture has evolved to encompass not only physical health but also social, intellectual, spiritual, environmental, financial, and digital health, together with modern concepts such as cyber health, ecological healthcare, health insurance, health management, telemedicine, and eHealth (fig. 3).

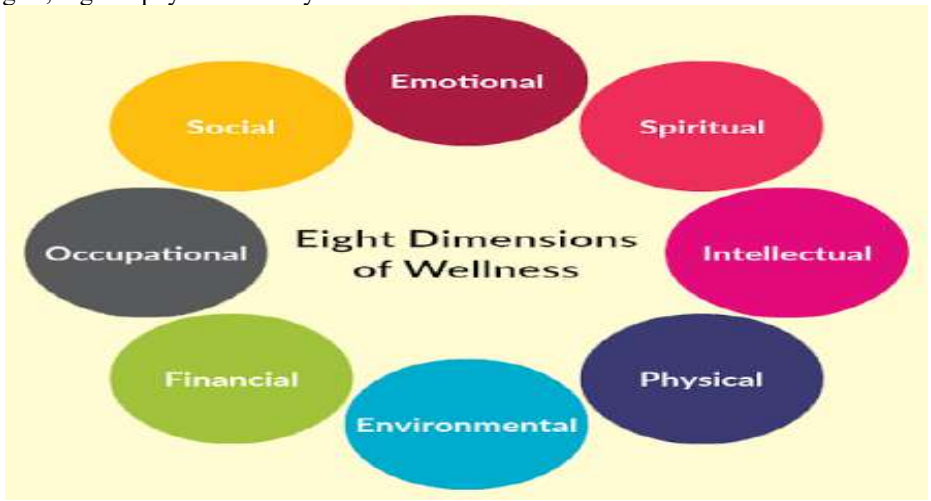


Figure 3. Classification of the main dimensions of wellness.

The growing acceptance of the wellness concept reflects this broader cultural transformation. Wellness is increasingly recognized as an accessible and person-centered approach to health promotion that encourages self-care, lifelong personal development, and integration with evidence-based preventive and rehabilitative interventions. Its flexibility, affordability, and compatibility with diverse health-promoting practices make it a practical framework for improving health-related quality of life and supporting sustainable healthy lifestyles.

Discussion

Wellness culture has been defined as a set of organizational policies, values, beliefs, customs, and supportive practices that promote healthy lifestyles and safe working environments within institutions and workplaces. Its primary objective is to foster health-oriented behaviors, improve employee well-being, and create organizational environments that support long-term physical and mental health (Fig. 4).

Figure 4*. Cultural norms shaping a healthy lifestyle*

Contemporary wellness culture should also be examined within the broader context of digital culture (cyberculture), where many health-related behaviors and social trends originate and rapidly disseminate. Digital technologies increasingly function as information management systems that facilitate access to health knowledge, encourage behavioral adaptation, and support health-related decision-making. Online platforms have become important environments for sharing physical activity programs, wellness interventions, nutritional guidance, and preventive health practices, making health culture more accessible than ever before. The interaction between humans and digital technologies has given rise to a distinct human–computer health subculture, which complements traditional verbal and written forms of health education. These virtual communities establish new social norms, values, and collaborative networks that influence health behavior and promote collective engagement in healthy lifestyles. This transition reflects a broader cultural shift from biomorphism toward technomorphism, accompanied by the emergence of new health-related cultural phenomena. Among the numerous values promoted within digital wellness communities, two appear particularly influential: social companionship through shared participation and the promotion of physical activity and health responsibility. Together, these factors strengthen motivation for sustained healthy behaviors and reinforce the principles of wellness culture in contemporary society.

Conclusion

Wellness culture has evolved into a fundamental component of the contemporary wellness paradigm, extending beyond traditional health promotion into the rapidly expanding digital environment. As digital health technologies and online wellness communities continue to develop, wellness culture is expected to play an increasingly important role not only for health-conscious individuals but also for healthcare systems and the wellness industry. Medical culture represents a specialized form of professional culture, whereas health culture is shaped by historical traditions, cultural heritage, and contemporary social values. Today, both concepts are increasingly integrated into cyberculture through digital health communication, eHealth services, telemedicine, and health management systems. Within this context, wellness culture may be regarded as an indicator of a modern, health-oriented society that values lifelong learning, personal responsibility, and holistic well-being. It reflects the characteristics of Homo cultus—an educated, culturally aware individual who actively promotes health, sustainable lifestyles, and continuous personal development.

Acknowledgement:

Conflict of Interest: *The author and the institution declared no conflict of interest.*

Financial Disclosure: *The article is under the implementation of project BG16RFPR002-1.014-0011 Sustainable Development of the Center of Excellence "Heritage BG," funded under the grant aid procedure BG16RFPR002-1.014 "Sustainable Development of Centres of Excellence and Centres of Competence, Including Specific Infrastructures or Their Associations from the National Roadmap for Scientific Infrastructure".*

Declarations *of informed consent have been signed regarding the publication of survey data.*

ChatGPT is used for English grammar revision and translation.

References

1. Aleksandrova V. (2021). The effect of swimming on health and physical activity in children with visual disabilities. Journal of Environmental Protection and Ecology 22(2): 847–857.

2. Aleksandrova, V. (2021a). Adaptirano pluvane za detsa s uvrezhdaniya*,* Monografiya, [In Bulgarian]. Ed. IPRESS, Sofia, 56-73.

3. Aleksandrova V. (2022). Wellness Aqua Programs Through Adapted Physical Activity and Sports for Children with Special Needs. Research Announcements 'Heritage BG' 3: 82–89.

4. Dimitrova, B. (2018). Research impact through scientific publications in wellness culture. Avangard Prima.

5. Dimitrova, B. (2018a). Wellness instructor competence standard: Unified outcomes acquired by learners: Knowledge, intellectual, and practical skills. Avangard Prima.

6. Dimitrova, B. (2019). Quality assessment of standards for wellness services and certified skills of specialized staff. Trakia Journal of Sciences, 17(2), 143–149. https://doi.org/10.15547 /tjs.2019.02.007

7. Dimitrova, B. (2019a). New smart educational model: Wellness instructor. Avangard Prima.

8. Dimitrova, B. (2019b). Recreative industry: The Bulgarian model for innovations in education and science. Smart Innovations in Recreational, Wellness Industry and Niche Tourism, 6–11. https://scjournal.globalwaterhealth.org/

9. Dimitrova, B. (2020). Relationships between education and innovations in the recreation industry in Bulgaria. Trakia Journal of Sciences, 18(2), 143–149. https://doi.org/10.15547/tjs.2020.02.007

10. Dimitrova, B., & Nesheva, I. (2021). Research to improve health care for women with normal pregnancy applying recreational wellness activity. *Trakia Journal of Sciences, 19*(Suppl. 1), 684–690

11. Dimitrova, B. (2025a). Mechanical and energy efficiency in wellness programs with cyclical movements. Series on Biomechanics, 39(1), 59–67. https://doi.org/10.7546/SB.01.08.2025

12. Dimitrova, B. (2025b). Niche tourism: Innovations and quality culture in specialized workforce development. German International Journal of Modern Science, (101), 88–93. https://doi.org/10.5281/zenodo.15124768

13. Dimitrova, B., et al. (2025). Scientific evidence for personalisation of SPA services at the cellular level. German International Journal of Modern Science, (100), 42–46. https://doi.org/10.5281/zenodo.15061591

14. Dimitrova, B. (2026). Assessing the health benefits of forest art therapy: Evidence from Bulgaria. Forestry Ideas, 32(1), 16–18.

15. Dimitrova, B., & Tomova, T. (2024). A wellness lifestyle, emotional intelligence, workplace, and leadership success. Smart Innovations in Recreational, Wellness Industry and Niche Tourism, 6(2), 51–56.

16. Ellis, S. (2013). The global wellness tourism report. Global Wellness Institute, 23-54 https://www.globalwellnesssummit.com/.

17. Global Wellness Institute. (2014). Global wellness tourism economy report. https://www.globalwellnesssummit.com/images/stories/gwi/GWI_2014_Global_Wellness_Tourism_Economy_Report_Final.pdf, 45-72

18. Nedelchev, I. (2019). Savremeni psihologicheski I filosofski aspekti na kulturizma I fitnesa. Ed. Agra, S., 22-31

19. Nesheva, I. (2023). Pregnancy and wellbeing. Trakia Journal of Sciences, Sofia. Volume 21, Supplement 1, Series Social Sciences, pp 231-235, doi:10.15547/tjs.2023.s.01.039 ISSN 1313-7069 (print), ISSN 1313-3551 (online)

20. Nesheva, I. (2023a). A wellness tool to perform healthy lifestyle practices In the Bulgarian school system. Natsionalno izdatelstvo Az Buki MON Sp. „Strategii na obrazovatelnata i nauchnata politika“ S. tom 31, nomer 5, s.560-572, ISSN 1314–8575 (Online); ISSN 1310–0270 (Print) - 0.2 (2022) Impact factor/ Q4 (2022) Rank by JCI, https://doi.org/10.53656/str2023-5-7-wel

21. Tomova, T. (2024). Modeling rituals through combined wellness influences. Smart Innovations in Recreational, Wellness Industry and Niche Tourism, 6(2), 15–24.

22. Tomova, T. (2025). The impact of manual wellness therapies and body massage: A stress relief effect. German International Journal of Modern Science, (105), 23–27.

23. Tomova, T., & Angelov, B. (2023). Wellness practices for healthy ageing. Trakia Journal of Sciences, 21(Suppl. 1), 445–450. https://doi.org/10.15547/tjs.2023.s.01.074

24. Vinarova, Z. (2015). Informatsionnata paradigma v zdraveopazvaneto [The information paradigm in healthcare]. [In Bulgarian]. Ed. Zahari Stoyanov, 45-87.

THE ECOBİOLOGY OF MEDİCİNAL PLANTS USED İN THE TREATMENT OF ORAL DİSEASES

Kamala Asadova,
Baku State University
ORCİD: 0000-0001-6531-3444
Vafa Alosmanova,
Baku State University
Sabina Azizova
Baku State University
DOI: 10.5281/zenodo.21837180

Abstract

Oral cavity diseases are characterized by the development of tumors and inflammatory processes. Inflammation is the most common pathology of the oral mucosa and also serves as a protective response of the organism. Inflammation can be classified into two main types: acute and chronic. This process depends on various factors, including the pathogen, its localization, activity, and the host's response. Morphologically, inflammation manifests in three forms: alternative, exudative, and proliferative.

Alternative inflammation involves tissue damage and destruction in the epithelium and connective tissue, characterized by dystrophic and necrotic cell processes, edema in vessel walls, as well as mucoid and fibrinoid degenerations. Exudative inflammation features vasodilation and swelling of endothelial cells, accompanied by edema and infiltration in the surrounding tissues. Proliferative inflammation is distinguished by the formation of mature connective tissue, where cells proliferate and differentiate.

For example, stomatitis, an inflammation of the oral cavity, can occur in individuals of all ages, affecting the cheeks, soft palate, hard palate, and at the base of the oral cavity. It presents with severe pain, inflammation, and ulceration, posing significant health risks. Clinically and morphologically, stomatitis has various forms.

Gingivitis and periodontitis are also widespread inflammatory diseases of the oral cavity. Gingivitis is an inflammation of the gums caused mainly by trauma, infections, chemicals, and allergic reactions, with bacterial pathogens such as Streptococcus, Fusobacterium, Actinomyces, Veillonella, and Treponema playing significant roles. The disease manifests through symptoms such as halitosis, redness, swelling, and bleeding of the gums, with the inflammation confined to soft tissues without affecting the periodontal ligament or alveolar bone.

Keywords: mucous membrane, infiltration, inflammation, bleeding, Streptococcus

Introduction

The role of phytotherapy in the treatment of oral diseases has always attracted scientific interest. Phytotherapy (from Greek: phyton – plant, therapeia – treatment) involves the use of plant-based raw materials and their biologically active constituents for therapeutic and prophylactic purposes. Historically, natural remedies have been employed both for treatment and to boost immunity, with traditional Azerbaijani medicine utilizing herbs such as mint, bay leaf, pomegranate peel, and sage.

Despite the increasing popularity of phytotherapy, research into its side effects and efficacy remains essential. Recently, the growing interest in medicinal plants is linked to their perceived better tolerability and lower toxicity compared to synthetic drugs, as well as their economic advantages. Although chemical medications often demonstrate higher efficacy, they are also associated with toxicity and adverse effects.

Phytotherapy plays a significant role in managing oral diseases, including stomatitis, gingivitis, periodontitis, and mucosal ulcers. Plants such as mint, thyme, chamomile, calendula, and black currant leaves are commonly used. Among these, gingivitis and periodontitis are the most prevalent. Gingivitis involves inflammation of the gums characterized by redness and swelling, while periodontitis is a more severe form leading to tissue destruction and potential tooth loss.

Aloe vera is one of the most utilized medicinal plants. Its leaves contain latex and gel; the gel, rich in polysaccharides, vitamins, and minerals, improves periodontal health, reduces inflammation, and diminishes bleeding. Turmeric (*Curcuma longa*) contains curcumin, which exhibits anti-inflammatory properties effective against gingivitis and periodontitis. For stomatitis, chamomile and calendula flowers are used due to their antiseptic properties, reducing inflammation and swelling. Infusions prepared with these herbs should be at appropriate temperatures to ensure efficacy and safety.

Thus, phytotherapy effectively contributes to the treatment and prevention of oral diseases.

Phytomedicinal Forms and Ecobiological Characteristics of Medicinal Plants

Medicinal plants, with their proven efficacy and safety, occupy a special place in modern medicine, especially in the prevention and treatment of oral pathologies. Their biocompatibility, due to active compounds such as alkaloids, flavonoids, and other bioactive substances, underpins their therapeutic effects, including anti-inflammatory and antimicrobial actions.

The bioactive content of medicinal plants depends on ecological factors such as the environment, climate, soil fertility, and geographical location where they grow- collectively known as their ecobiological characteristics. These factors influence both the growth and medicinal properties of the plants.

Salvia officinalis (Sage): A perennial herb reaching heights of 50–80 cm, with square stems and opposite leaves. The plant contains 1–2.5% essential oils, saponins, vitamins, and flavonoids. Its leaves are used

for their anti-inflammatory and antimicrobial effects, especially in treating gingivitis and other oral inflammations.

Rosmarinus officinalis (Rosemary): Growing up to 1 meter, with a woody, branched stem, rich in essential oils and tannins. Rosemary infusions are used for mouth inflammation and also improve digestion and soothe the nervous system.

Rubus fruticosus (Blackberry): A widely distributed perennial shrub with prickly stems. Its leaves and fruits are used to treat cardiovascular issues, swelling, and oral inflammations. The leaves are harvested before flowering for medicinal preparations.

Thymus vulgaris (Common Thyme): An aromatic, creeping herb with a height of 20–35 cm. Its essential oil contains thymol, which has antiseptic and anti-inflammatory properties, making it useful in treating laryngitis, bronchitis, and oral inflammations.

Results and Discussion

Plant-based medicines derived from medicinal herbs are gaining global prominence. Their use is especially prevalent in developing countries, where they fulfil the majority of healthcare needs. Developed nations also rely on phytochemicals as essential components of pharmaceutical preparations. The demand for herbal medicines and natural products is increasing due to their perceived safety and lower toxicity.

Research indicates that approximately 15,000 medicinal plant species are under threat due to overharvesting, habitat destruction, and unsustainable collection practices-particularly in Asia, Europe, and Africa. Globally, around 50,000–80,000 plant species are used in phytotherapy, with many at risk of extinction. The loss of these species jeopardizes the availability of valuable medicinal resources.

The conservation of medicinal plants involves *in situ* measures- protection within their natural habitats- and *ex situ* strategies, including seed banks, botanical gardens, and nurseries. *In situ* conservation preserves natural ecosystems, maintaining biodiversity and ecological functions, while *ex situ* methods safeguard genetic material for future reintroduction and sustainable use.

In conclusion, the high prevalence of oral diseases necessitates effective treatment and preventive strategies, including phytotherapy. The incorporation of medicinal plants such as chamomile, sage, mint, thyme, oak bark, and blackberry leaves- owing to their antiseptic, anti-inflammatory, astringent, and antimicrobial effects- has proven beneficial. The active compounds in these plants form the basis of their therapeutic effects, emphasizing the importance of proper usage to maximize benefits and minimize adverse reactions.

However, the natural reserves of medicinal plants face significant threats from anthropogenic impacts, including overharvesting and habitat destruction. Their sustainable utilization and conservation are crucial for ensuring the continued availability of these valuable resources. Strategies such as protected areas, botanical gardens, and seed banks are vital components of global efforts to conserve medicinal plant biodiversity and ensure their future use in medicine.

References

1. Alosmanova V.M. Böyük Qafqazın şərq hissəsinin geofit bitkilərinin taksonomik tərkibi haqqında, «Tətbiqi biologiyanın problemləri» resp.elmi konf.(27 -28 aprel), BDU nəşr., 2007, səh.178.

2. Alosmanova V.M. Böyük Qafqazın şərq hissəsində erkən yazda çiçəkləyən geofit bitki növlərinin yayılması və fenologiyası, AMEA Mərkəzi Nəbatat Bağının elmi əsərləri, XI cild, 2013, səh.266-270.

3. Alosmanova V.M. Böyük Qafqazın şərq hissəsində rast gəlinən geofitlərin endemizmi, Bakı Universitetinin xəbərləri, Təbiət elmləri seriyası, №3-4, 2014, səh.83-87.

4. Alosmanova V.M., Azərbaycan MEA-nın müxbir üzvü İbadlı O.V. Böyük Qafqazın şərq hissəsinin yay otlaqları, onlardan səmərəli istifadə olunması və yaxşılaşdırılma yolları, AMEA «Məruzələr», LXVII cild, №4, 2011, s.67-72.

5. Alosmanova V.M. Şamaxı və Qobustan rayonlarının yay otlaqlarının müasir vəziyyəti və onların mühafizəsi, Akademik Həsən Əliyevin 105 illik yubileyinə həsr olunmuş «Ekologiya: Təbiət və cəmiyyət problemləri» II Beynəlxalq elmi konfrans, Bakı, 7-8 noyabr, 2012, s.339-340

6. Alosmanova V.M., İbadlı O.V. Dağlıq Şirvan rayonlarının geofit bitkilərinin taksonomik tərkibi və biomüxtəlifliyinin öyrənilməsi, Azərbaycan Milli Elmlər Akademiyasının Xəbərləri (biologiya elmləri), 2007, №3-4, s.49-54.

7. Alosmanova V.M. Böyük Qafqazın şərq hissəsində rast gəlinən bitki növlərinin qurşaqlar üzrə paylanması, AMEA Mərkəzi Nəbatat Bağının elmi əsərləri, XIII cild, 2015, səh. 112-116.

8. Alosmanova V., Asadova K., Mammadova Z. (2025). Phytocoenoses formed by species of the genus Trigonella L. in the flora of Azerbaijan. III İnternational Apitherapy and Nature Congress. İnstitute of Botany of the Ministry of Science and Education of the Republic of Azerbaijan. pp.287-289

9. Alosmanova, V.M., & Bakhshiyev, V.S. (2024). Study of plant groupings formed by species of the genus Suaeda Forssk. ex Scop. in the flora of Azerbaijan. In Proceedings of the 12th International Scientific Conference “Achievements and Challenges in Biology (ACB)”, dedicated to the 105th anniversary of Baku State University and the 90th anniversary of the Faculty of Biology, within the framework of the “Year of Solidarity for a Green World”, Baku, pp. 880–884.

10. Asadova, K. (2026). CURRENT STATUS AND RESTORATION CHALLENGES OF RIPARIAN FORESTS IN THE KURARAZ LOWLAND (AZERBAIJAN). German International Journal of Modern Science/Deutsche Internationale Zeitschrift für Zeitgenössische Wissenschaft, (126), 7.

11. Asadova, K.A. (2026). DESERT AND SEMI-DESERT PHYTOCENOSES OF THE MIL PLAIN: IMPLICATIONS FOR WINTER PASTURE MANAGEMENT. German International Journal of Modern Science/Deutsche Internationale Zeitschrift für Zeitgenössische Wissenschaft, (122), 9.

12. Asadova, K. (2019). Bioecological Features of Some Feed, Poisonous and Noxious Plants on the Winter Pastures of the Mil Steppe in Azerbaijan. Khazar Journal of Science and Technology (KJSAT), Volume 3 №2, 56-62 DOI: 10.5782/2520-6133.2019.3.2.56

13. Asadova, K. (2026). CURRENT STATUS AND RESTORATION CHALLENGES OF RIPARIAN FORESTS IN THE KURARAZ LOWLAND (AZERBAIJAN). German International Journal of Modern Science/Deutsche Internationale Zeitschrift für Zeitgenössische Wissenschaft, (126), 7.

14. Gurbanov Elshad, & Asadova Kamala (2020). TAXONOMIC SYNOPSIS OF SALSOLA GENUS (MIL PLAIN, AZERBAIJAN). Бюллетень науки и практики, 6 (11), 78-84.

15. Gurbanov, E. M., Alosmanova, V. M., & Asadova, K. A. (2024). Effect of salinity of the soil of Kur-Araz lowland on the productivity of seepweed (Suaeda Forsk.) species. In 2nd International Conference: Conservation of Eurasian Biodiversity (pp. 2-4).

16. Ismayilova, M., Mammadova, R., & Mammadova, A. (2025). Fitoindication of environmental quality utilizing the MAPLE software package. Baku State University Journal of Life Sciences & Biology, 2 (1), 1-4.

17. Mammadova Z., Alosmanova V., Asadova K. (2026) THE CURRENT STATE OF THE FLORA OF LAKE SARYSU (AZERBAIJAN). Бюллетень науки и практики / Bulletin of Science and Practice https://www.bulletennauki.ru. T.12. №4 https://doi.org/10.33619/2414-2948/125.

18. Mammadova, Z. (2025). Phytocenosis found in the leguminous valley meadow vegetation in the winter pastures of the Mil-Karabakh massif (Beylagan and Agjabadi) of Azerbaijan, their species composition and effective use. Baku State University Journal of Life Sciences & Biology, 2(1), 10-21.

19. Mammadova, Z. J. (2026). IMPACT OF CLIMATE CHANGE ON LEGUME-DOMINATED PHYTOCENOSES IN THE ALPINE GRASSLANDS AND MEADOWS OF AZERBAIJAN. German International Journal of Modern Science/Deutsche Internationale Zeitschrift für Zeitgenössische Wissenschaft, (122), 13.

20. Mammadova, Z.J., Gurbanov, E.M., & Asadova, K.A. (2017). Leguminous phytocenosis distributed in hole-meadow vegetation of Azerbaijan and their agricultural importance. Europ. Acad. Res, 1, 580-594.

21. Mammadova, A. (2017). Development of Fieldwork Activities to Educate the Youth for the Biological and Cultural Preservation in Rural Communities of Ishikawa Prefecture, Japan. International Journal of Environmental and Science Education, 12(3), 441-449.

22. Vafa Alosmanova, Zulfiyya Mammadova, Kamala Asadova, Vazeh Bakhshiyev. ASSESSMENT OF MORPHOLOGICAL DIFFERENCES IN FRUITS OF SUAEDA (SUAEDA FORSSK. EX SCOP.) SPECIES IN THE FLORA OF AZERBAIJAN REPUBLIC. Deutsche internationale Zeitschrift für zeitgenössische Wissenschaft. №108 2025. Pp. 8-10. DOI: 10.5281/zenodo.16086109

23. Kamalya, A. (2021). CHARACTERISTICS OF THE HOLE-MEADOW VEGETATION OF KUR-ARAS LOWLAND (AZERBAIJAN). Бюллетень науки и практики, 7(11), 51-56.

24. Gurbanov, E. M., & Asadova, K. A. (2017). CONTEMPORARY ASSESSMENT OF THE SPECIES CONTENT OF ENDEMICS AND SUBENDEMICS OF MIL STEPPE FLORA OF AZERBAIJAN.

PEDAGOGICAL SCIENCES

WELLNESS AND NUTRITION AS DETERMINANTS OF SPORTS PERFORMANCE

Maya Chipeva
Assoc. Prof., D. Sc., Department of Physical Education and Sports, Technical University of Sofia, Bulgaria
ORCID ID: 0000-0002-4256-8759
DOI: 10.5281/zenodo.21837235

Abstract
Nutrition is a key determinant of athlete health, recovery, and sports performance, influencing the metabolic and physiological adaptations required for training. This review examines the relationship between wellness, nutrition, and athletic performance, emphasizing nutrient absorption, food composition, and personalized dietary strategies. Evidence-based nutritional assessment, including dietary recalls, food frequency questionnaires, supplementation studies, and individualized nutrition plans, is discussed in relation to recovery and performance outcomes. Attention is given to the role of macronutrients, micronutrients, and ergogenic aids, including creatine, beta-alanine, and omega-3 fatty acids, in enhancing exercise adaptation. The findings highlight that optimal performance requires a holistic approach integrating nutrition, adequate recovery and individualised dietary management. Personalised nutrition is essential for improving health, maximizing performance, and supporting long-term athletic development.

Keywords: sports nutrition; performance; nutrient absorption; personalised wellness.

Introduction

Nutrition fundamental component of sports training, deserving special attention and becoming foundational from a very early age for every athlete (1, 6, 8). It aims to optimally supply the body with nutrients, which is why it is associated with adhering to several essential principles of athlete nutrition (4, 5, 15). These principles are mainly derived from rational and healthy eating and aim to maintain excellent athletic shape and good health (9, 19, 21). Proper nutrition directly influences the enhancement of body capacity, abilities, and sports performance. Understanding the principles of dietetics that aid in developing an athlete is crucial for achieving high results. Becoming a good athlete is not about spending one or two hours at the stadium or in the gym but about maintaining a 24-hour regimen for the body (10, 13, 22). For this reason, the athlete must be responsible for their performance—diet, sleep, recovery, behavior, and attitude towards the training and competitive process (3, 9, 14). Physical labor and regular sports activities boost self-esteem towards better motivation and willpower, better time management, and more rational achievement of daily goals (2, 20, 23). Nutrition is a fundamental aspect of athletic training, requiring special attention, and is crucial from an early age for every athlete (11, 15, 17). Before embarking on the path of professional sports, children and their parents must carefully evaluate whether they can endure the demands of this challenging journey, as the work is grueling, the sacrifices are significant (7, 11, 16). The competition in modern elite sports is fierce (12, 18). Reaching the pinnacle of a sports career requires substantial sacrifices, which not everyone is willing to make. In Bulgaria, nutrition is not well integrated into both youth and professional sports. There is an overemphasis on training, exertion, and training methods, while recovery takes a backseat, often relying on traditional methods such as massage and sauna. Sleep also tends to be underestimated.

Methods

Nutritional Assessment: Dietary needs personalised analysis of Food diaries and Dietary recall: Collect detailed information on athletes' dietary habits through 24-hour dietary recalls or food frequency questionnaires. Analyse the data for macronutrient and micronutrient intake, caloric distribution, and adherence to recommended dietary guidelines

*Nutritional Intervention Trials: C*ontrolled feeding trials Implements tightly controlled dietary interventions where athletes consume predesigned meals tailored to specific performance goals. Monitor their effects on physiological and psychological outcomes.

Supplementation Studies: Investigate the role of specific supplements (e.g., creatine, beta-alanine, omega-3 fatty acids) in enhancing recovery, reducing traumatism or improving endurance.

Customized Nutrition Plans: Tailor diets based on individual athlete needs, genetic predispositions, and sports demands. Evaluate outcomes to refine personalized nutrition strategies.

Results

Nutrition is a fundamental determinant of physiological function, athletic performance, recovery, and long-term health. Evidence indicates that a balanced dietary intake, comprising appropriate proportions of carbohydrates, proteins, fats, vitamins, minerals, and adequate hydration, is essential for optimizing metabolic processes and reducing injury risk (17, 18). Nutritional strategies should be individualized according to the biomechanical, physiological, and energetic demands of specific sports, considering factors such as endurance, strength, power, and intermittent exercise characteristics. Athlete-specific variables, including body composition, metabolic profile, playing position, age, and training objectives, should also inform dietary planning. The judicious use of evidence-based dietary supplements may further support performance and re-

covery when tailored to individual requirements. Conversely, excessive consumption of highly processed foods rich in saturated fats, refined sugars, preservatives, and additives may impair metabolic efficiency and compromise athletic adaptation. Therefore, priority should be given to nutrient-dense foods, including lean proteins, fish, whole grains, fruits, vegetables, nuts, and healthy fats, which provide the substrates necessary for energy production, tissue repair, immune function, and physiological resilience. Nutrient timing should likewise reflect sport-specific demands, with carbohydrate availability optimized for high-intensity and explosive activities, whereas endurance disciplines may require greater reliance on fat metabolism. Team sports characterized by intermittent exercise patterns require balanced nutritional approaches that support both aerobic and anaerobic energy systems. Effective nutritional management should be delivered through an interdisciplinary framework involving dietitians, physicians, psychologists, exercise physiologists, and coaches. Such collaboration enables individualized nutritional interventions that enhance performance, accelerate recovery, support injury prevention, and promote sustainable athlete development throughout the competitive career.

1. **Athlete's Weight**: An athlete's body weight is influenced by genetics, lifestyle, environment, social conditions, family background, and education. Maintaining and achieving an optimal weight is a personal priority linked to persistence, motivation, willpower, and mental stability. In many sports, maintaining optimal or low weight is crucial, often requiring changes in diet and strict adherence to healthy eating principles.

2. **Simplicity Daily, Variety Weekly and Monthly**: Breakfasts, lunches, and dinners should be consistent in composition to ensure proper digestion and nutrient absorption. This approach aligns with the concept of balanced eating. An athlete's daily menu should provide the necessary energy and contain a proper balance of nutrients, vitamins, and trace elements. The challenge in preparing weekly and monthly menus is ensuring the food is diverse, high-energy, and balanced.

3. **Breakfast**: It should be consumed at least two hours before the morning workout and primarily consist of carbohydrates to provide energy. It may include warm drinks like tea and milk, sweetened with a spoonful of sugar or honey. Pre-workout meals should be concentrated, high-calorie, easily digestible, and small in volume, rich in carbohydrates and vitamins. Breakfast should account for about 25-30% of daily intake. If there's an afternoon snack, it should be light, comprising about 10% of the day's food.

4. **Lunch**: This depends on the athlete's training schedule. If lunch is after a workout, it should include a larger quantity of food (40-45% of daily intake) with higher protein, fat, and mineral content. If lunch precedes training, it should be smaller (30-35% of daily intake), with more carbohydrates and easily digestible food.

5. **Dinner**: Dinner should be protein-rich and eaten before 7:30 PM. If the sport requires muscle mass gain, an additional protein product can be consumed 1-2 hours after dinner. A high-protein dinner is based on the idea that amino acids are better absorbed during sleep when growth hormone is secreted in larger amounts. In a three-meal day, dinner should comprise 25-30% of total food intake, or 20-25% if there's an afternoon snack. If the athlete has a workout or event in the afternoon, dinner should be at least an hour after and should make up 25-30% of the daily intake.

6. **Composition of Food**: Nutrition should provide the body with all essential nutrients: proteins, carbohydrates, fats, vitamins, minerals, and antioxidant compounds. If the athlete needs to follow a low-energy diet, energy intake is reduced primarily from fats and carbohydrates.

Carbohydrates: These are the body's primary fuel. The body stores carbohydrates as glycogen in the muscles and liver. During intense training, this glycogen is depleted, and the body starts drawing energy from body fats and proteins. Excess sugar can lead to conversion into fats. Hence, it's important to maintain an optimal carbohydrate intake. This amount should be sufficient to replenish the body's glycogen stores and support performance during physical activity. Endurance athletes have the greatest need for carbohydrates, while gymnasts and weightlifters require the least (tab. 1).

Table 1.

Nutrition for Athletes, by IOC, 2021 standards.

Training Load	Description of Load	Carbohydrate Intake
Light	Low-intensity activities or activities requiring specific skills	3-5 g/kg/day
Moderate	Moderately intensive programs (around 1 hour daily)	5-7 g/kg/day
High	Endurance programs (1-3 hours/day of moderate to high intensity)	6-10 g/kg/day
Very High	Extremely high loads (4-5 hours/day of moderate to high intensity)	8-12 g/kg/day

These are the primary building blocks of the body. They form muscle tissue and contribute to the construction of structural proteins and enzymes. For athletes focusing on strength development and muscle building, proteins are a key component. This can be effective only with the right combination of high protein intake and substances that support anabolic processes. In sports nutrition, not only the quantity but also the quality of proteins is crucial, meaning they should contain all the essential amino acids necessary for the human body, integral to nerve tissue, hormones, and more. The more trained an organism is, the more effectively and quickly it utilizes fats for energy needs. Athletes like marathon runners, cyclists, ski jumpers, and swimmers have the highest fat requirements. It is recommended to

reduce animal fats to 10%, with the remainder coming from dairy, fish, and plant sources (tab. 2).

Table 2.

Protein Nutrition for Athletes, in accordance with the motor intensity by IOC, 2021 standards.

Training Load	Protein Intake
Low physical activity	0.8 g/kg/day
Regular training program	1.0 g/kg/day
Endurance sports with intensive training program	1.2-1.6 g/kg/day
Endurance sports with very intensive or competitive training program	2.0 g/kg/day
Strength sports with intensive training program	1.2-1.7 g/kg/day
Young athletes	2.0 g/kg/day

Vitamins and Minerals: These are essential for the proper functioning of the body's metabolism. They are crucial for the correct operation of all organs and systems; deficiency can lead to imbalances and metabolic issues. Therefore, food should contain adequate vitamins and minerals, mainly sourced from fresh fruits and vegetables. Sports activities significantly increase the demand for these substances, and often they are supplemented through dietary supplements.

7. **Fluid Intake**: Water is necessary for all biochemical processes in the body. To maintain optimal physical condition, proper hydration is crucial. Athletes should drink fluids before, during, and after physical exertion to stay well-hydrated. The amount of fluid intake should be carefully adjusted according to physical activity, air temperature, and other factors influencing fluid loss.

8. **Eating Fruits on an Empty Stomach**: Due to their tendency to ferment quickly, fruits are best consumed half an hour to an hour before meals. Vegetables and salads should be eaten during main meals and seasoned with olive oil.

9. **Combining Foods**: There are various theories about food combinations, ranging from those that completely exclude combining certain foods to those that advocate mixing many different foods. Rational nutrition combines hard-to-digest foods with vegetables and spices for easier digestion. While there is no scientific evidence of chemical incompatibility between different foods, there is evidence of nutrient competition during absorption, such as fats hindering glucose transport, sugars interfering with fat absorption, and two types of sugars competing with each other.

10. **Self-Control**: This is a crucial factor for all athletic success. An athlete's diet is an element of their personal freedom, but to achieve high sports performance, they must adhere to a specific regime and principles.

Discussion

Nutrition plays a critical role in the performance, recovery, and overall health of athletes. A well-designed nutrition plan tailored to the specific demands of an athlete's sport, training intensity, and individual physiology can enhance performance, reduce the risk of injuries, and promote long-term well-being. This discussion highlights key nutritional considerations for athletes, focusing on macronutrient balance, hydration, supplementation, and timing of nutrient intake.

Macronutrient Requirements

1. *Carbohydrates:* Carbohydrates serve as the primary energy source for athletes, particularly during high-intensity and endurance activities. Adequate carbohydrate intake supports glycogen replenishment, delays fatigue and improves endurance performance. For athletes engaging in light, moderate, or high-intensity training, carbohydrate needs vary between 3-12 g/kg/day, depending on the duration and intensity of activity. Insufficient carbohydrate intake can lead to reduced glycogen stores, resulting in diminished performance and delayed recovery.

2. *Proteins:* Proteins are essential for muscle repair, recovery, and growth. Athletes require higher protein intakes than the general population, ranging from 1.2-2.0 g/kg/day depending on their training load and type of sport. Endurance athletes benefit from protein to prevent muscle breakdown during prolonged activity, while strength athletes require protein to support muscle hypertrophy and repair. Timing protein intake post-exercise is particularly crucial for maximizing muscle protein synthesis.

3. *Fats:* Fats are a key source of energy, especially during prolonged, low-to-moderate-intensity exercise. Healthy fat intake supports hormonal balance and the absorption of fat-soluble vitamins. Athletes should aim for 20-35% of their daily caloric intake from healthy fats, with an emphasis on sources such as avocados, nuts, seeds, and fatty fish. Balancing fat intake is essential to prevent gastrointestinal distress during training or competition.

Hydration

Proper hydration is vital for maintaining performance and preventing dehydration, which can lead to fatigue, reduced cognitive function, and heat-related illnesses. Athletes should monitor fluid intake before, during, and after training or competition. Electrolyte replacement is crucial for prolonged activities to restore sodium, potassium, and other minerals lost through sweat. Individual hydration needs vary based on factors such as climate, intensity, and sweat rate, necessitating personalized hydration strategies.

Micronutrients and Supplements

1. *Micronutrients:* Vitamins and minerals, such as calcium, iron, magnesium, and vitamin D, are essential for optimal performance and recovery. Iron, for instance, is crucial for oxygen transport and energy production, particularly in endurance athletes. Female athletes and those following plant-based diets may require additional attention to micronutrient intake.

2. *Supplements*: While whole foods should be the primary source of nutrients, certain supplements can be beneficial for athletes when used appropriately. Examples include:

❖ Creatine for improved strength and power output.

❖ Caffeine for enhanced endurance and focus.

❖ Beta-alanine for buffering muscle acidosis during high-intensity efforts.

❖ Athletes should consult with a nutritionist or healthcare provider before incorporating supplements into their regimen to ensure safety and efficacy.

Nutrient Timing

The timing of nutrient intake plays a critical role in optimizing performance and recovery.

❖ Pre-exercise: A meal rich in carbohydrates and moderate in protein, consumed 2-3 hours before activity, provides energy and prevents hunger.

❖ During exercise: For prolonged activities, consuming easily digestible carbohydrates (e.g., sports drinks or gels) helps maintain energy levels.

❖ Post-exercise: Consuming carbohydrates and protein within 30-60 minutes after exercise accelerates glycogen replenishment and muscle repair.

Individualisation and Sport-Specific Needs

Athletes' nutritional requirements vary based on their sport, training schedule, and personal goals. Endurance athletes prioritize carbohydrates for sustained energy, while strength athletes focus on protein to support muscle growth. Additionally, young athletes, female athletes, and those with specific dietary preferences (e.g., vegetarian or vegan diets) require tailored nutritional strategies to meet their unique needs.

Conclusion

Nutrition represents a fundamental component of athletic performance, recovery, and long-term health. Evidence indicates that individualized nutritional strategies integrating balanced macronutrient intake, adequate hydration, optimal micronutrient status, and appropriate nutrient timing enhance physiological adaptation, support recovery, and improve competitive performance. Because nutritional requirements differ according to sport-specific demands, training load, and individual characteristics, dietary interventions should be tailored to each athlete's physiological profile and performance objectives. Future research should investigate personalized, evidence-based nutritional approaches and evaluate their long-term effects on performance, injury prevention, and overall health. Strengthening nutrition education and ensuring access to qualified sports nutrition professionals are essential for translating scientific evidence into practice, thereby maximizing athletic potential and supporting sustainable athlete development throughout the competitive lifespan.

Acknowledgement:

Conflict of Interest: *The author and the institution declared no conflict of interest.*

Financial Disclosure: *The article is under the implementation of project BG16RFPR002-1.014-0011 Sustainable Development of the Center of Excellence "Heritage BG," funded under the grant aid procedure BG16RFPR002-1.014 "Sustainable Development of Centres of Excellence and Centres of Competence, Including Specific Infrastructures or Their Associations from the National Roadmap for Scientific Infrastructure"*

Declarations *of informed consent have been signed regarding the publication of survey data.*

ChatGPT is used for English grammar revision and translation.

References

1. Aladzhov, K. (2014). Pazi si zdraveto na mladini za da si dobre na starini. [In Bulgarian]. S.,12-31 Simolini.

2. Aleksandrova V. (2021). The effect of swimming on health and physical activity in children with visual disabilities. Journal of Environmental Protection and Ecology 22(2): 847–857.

3. Aleksandrova, V. (2021a). Adaptirano pluvane za detsa s uvrezhdaniya, Monografiya, [In Bulgarian]. Ed. IPRESS, Sofia, 56-73.

4. Aleksandrova V. (2022). Wellness Aqua Programs Through Adapted Physical Activity and Sports for Children with Special Needs. Research Announcements 'Heritage BG' 3: 82–89.

5. Dimitrova, B. (2018). Research impact through scientific publications in wellness culture. Avangard Prima, Sofia, p.33-56.

6. Dimitrova, B. (2019). Intelligent competencies for niche tourism [Monograph, in Bulgarian]. Avangard Prima, 54-72.

7. Dimitrova, B. (2019a). Quality assessment of standards for wellness services and certified skills of specialised staff. Trakia Journal of Sciences, 17(2), 143–149. https://doi.org/10.15547/tjs.2019.02.007

8. Dimitrova, B., et al. (2020). Dynamics of well-being and happiness indices: Comparative analysis based on global databases and United Nations reports [Monograph, in Bulgarian]. Avangard Prima, Sofia, p.96-104.

9. Dimitrova, B., et al. (2021). Smart cognitive toolkit: External assessment of professional competencies for specialised staff in niche tourism [Monograph, in Bulgarian]. NSA Press, Sofia, p.87-102.

10. Dimitrova, B., I. Nesheva 2021. Research to improve health care for women with normal pregnancy applying recreational wellness activity. Trakia Journal of Sciences, 19(1):684–690,.

11. Dimitrova, B. (2023). Educational policy, specialised staff, innovations and the recreational industry. Strategies for Policy in Science and Education, 31(5), 532–546. https://doi.org/10.53656/str2023-5-6-imp

12. Dimitrova, B., & Tomova, T. (2024). A wellness lifestyle, emotional intelligence, workplace, and leadership success. Smart Innovations in Recreational, Wellness Industry and Niche Tourism, 6(2), 51–56.

13. Dimitrova, B. (2025). Mechanical and energy efficiency in wellness programs with cyclical movements. Series on Biomechanics, 39(1), 59–67. https://doi.org/10.7546/SB.01.08.2025

14. Dimitrova, B. (2025a). Niche tourism: Innovations and quality culture in specialized workforce development. German International Journal of Modern

Science, (101), 88–93. https://doi.org/10.5281/zenodo.15124768

15. Dimitrova, B., et al. (2025). Scientific evidence for personalisation of SPA services at the cellular level. German International Journal of Modern Science, (100), 42–46. https://doi.org/10.5281/zenodo.15061591

16. Dimitrova, B. (2026). Assessing the health benefits of forest art therapy: Evidence from Bulgaria. Forestry Ideas, 32(1), 16–18.13. Maughan, R. and Burke L. (2012). Nutrition for Athletes, Book. Ed. NY

17. Melshina, L., Balashov N. (2017). Lechebna fizkultura. Ed. Homo Futuris, Sofia

18. Nedelchev, I. (2019). Savremeni psihologicheski I filosofski aspekti na kulturizma I fitnesa.

19. Nesheva, I. (2023). Pregnancy and wellbeing. Trakia Journal of Sciences, Sofia. Volume 21, Supplement 1, Series Social Sciences, pp 231-235, doi:10.15547/tjs.2023.s.01.039 ISSN 1313-7069 (print), ISSN 1313-3551 (online)

20. Nesheva, I. (2023a). A wellness tool to perform healthy lifestyle practices In the Bulgarian school system. Natsionalno izdatelstvo Az Buki MON Sp. „Strategii na obrazovatelnata i nauchnata politika“ S. tom 31, nomer 5, s.560-572, ISSN 1314–8575 (Online); ISSN 1310–0270 (Print) - 0.2 (2022) Impact factor/ Q4 (2022) Rank by JCI, https://doi.org/10.53656/str2023-5-7-wel

21. Tomova, T. (2024). Modeling rituals through combined wellness influences. Smart Innovations in Recreational, Wellness Industry and Niche Tourism, 6(2), 15–24.

22. Tomova, T. (2025). The impact of manual wellness therapies and body massage: A stress relief effect. German International Journal of Modern Science, (105), 23–27.

23. Tomova, T., & Angelov, B. (2023). Wellness practices for healthy ageing. Trakia Journal of Sciences, 21(Suppl. 1), 445–450. https://doi.org/10.15547/tjs.2023.s.01.074

SOCIAL SCIENCIES

HEALTH PREVENTION IN AQUATIC ENVIRONMENT

Dimitrova Bistra
Prof, D. Sc. Faculty of public health, health care and Tourism
National Sports Academy "Vassil Levski", Bulgaria
ORCID ID: 0000-0003-3152-9831
DOI: 10.5281/zenodo.21837301

Abstract

Aquatic environments and hydrotherapy represent evidence-based natural resources that contribute to disease prevention, functional recovery, and health promotion. This study investigated the preventive effects of standardized aquatic interventions in 108 elite athletes treated at the Center for the Recovery of Bulgarian Olympic Athletes. The intervention protocol comprised therapeutic showers, underwater massage, jacuzzi, pearl baths, mineral water therapies, and structured aquatic exercise. Statistical analyses were performed using Microsoft Excel Professional Plus 2010 and XLSTAT 2015, with data normality verified by the Shapiro–Wilk test ($\alpha = 0.05$). The findings demonstrate that regular aquatic therapy enhances physiological adaptation, supports immune function, accelerates recovery, and promotes healthy aging. Furthermore, Bulgaria's abundant mineral springs and therapeutic peloids provide scientifically validated resources for preventive healthcare, rehabilitation, sustainable wellness tourism, and evidence-based public health strategies.

Keywords: aquatic environment; hydrotherapy; recreation; mineral waters; Spa culture.

Introduction

The physical and psychological health of people reflects on the whole society, but it is a matter of personal choice and culture to achieve a healthy balance (6, 13). Citizens with balanced health are able to work, which helps them become better professionals and be more intellectually innovative than others suffering from chronic health issues. (7, 15, 20). Personal self-esteem and cheerfulness emotionally affect the connection with nature and the ecological balance of the planet (1, 2, 16). The recreational industry around the world needs specialized staff with degrees in accredited programs (5, 9, 17). The dynamics of the global wellness economy are maintained by 180,000 staff per year with interdisciplinary professional competencies (8, 11, 12). These causal relationships are fundamental to the modern world and do not require arguments other than statistical information (14, 18). Within the EU alone, more than 350-400 million people of all ages practice recreational motor and modeling products / practices through a variety of Wellness & SPA methods (3, 19). Water treatments are a major tool for hydrotherapy. In this paper we propose them as a health-preventive or cosmetic procedure. In this sense, they improve the quality of life when applied in everyday life and the quality of leisure when offered in travel packages (13). Bulgaria is rich in mineral springs, which are a natural and ecological source of enriched chemical waters. Thermal treatment is a field in tourism that is yet to be developed and has a proven health-preventive and recreational effect. Another wet procedure typical of our country is mud therapy or mud treatment. A mud mixture called humus or sedimentary mud from mineral springs is usually used. In Europe, this type of recreation with warm or indifferent temperature of the mud is little known and is of interest for tourist activities.

Methods

Participants. One hundred and eight elite athletes, men and women, with respective mean ages of 24.4 and 23.2 years were studied. All were subjected to the same experimental task applying water influences. The primary data are collected at the Center for the Recovery of Bulgarian Olympic Athletes, and we publish details with the permission of the Director (signed declaration of informed consent). For our statistical analysis, we used the EXCEL program of Microsoft Office Professional Plus 2010, with statistical program XLSTAT 2015. We checked the normality of the distribution of our data using the Shapiro-Wilk normality statistical method to test our working hypothesis. It assumes that the inclusion in the daily schedule of water effects (hydro therapies, jets, tangentor, jacuzzi, pearl bath, enriched water, water motor programs with and without device) will activate the body's immune and tempering mechanism, thus achieving a healthy lifestyle. In this study, the calculated p-value is greater than the significance level alpha ($\alpha = 0.05$), Therefore, the null hypothesis (H0) for the health impact of the aquatic environment was approved.

Results

Bulgaria has diverse in content and healing properties mineral springs, peloids (mud therapy or mud treatment with clay or sedimentary mud from mineral springs), peloides, which are natural and ecological source of health from nature. Thermal treatment is a field in Recreation (health prevention) and tourism, which is to be developed and has a proven health-preventive and antiaging effect. The general classification of the most common types is determined by the temperature of the water, its chemical composition and the mechanical force of impact when using specialized equipment. The mechanism of the physiological impact of the aquatic environment is determined mainly by its physical properties. The density and thermal conductivity of water make it an effective environment for health prevention, recreation and a positive cosmetic effect (Fig. 1).

•ACTIVATING THE ACTIVITY OF THE SWEATING GLANDS
HOT MINERAL OR ENRICHED WATER
SEA LUGA OR SIMULATION
•ACTIVE INTAKE OF SALTS AND MINERALS THROUGH THE SKIN
•CAUSE ACTIVE HYPEREMIA
HEALING PELOIDS: MUD, HUMA, RIVER OR LAKE SEDIMENTS
FOREST SPRING WATERS: WATERFALLS, STREAMS, RIVERS
INCREASED EXCHANGE OF THE BODY SUBSTANCES

Figure 1. *Recreational and cosmetic function of the water procedures impact (with hot water).*

The body's ability to give off and receive heat is activated as a result of the temperature contrast between body temperature and that of the aquatic environment. Under the influence of water procedures, enzyme systems are activated in the skin that directly affect vascular tone and blood circulation. This complex mechanism is realized by the emergence of nerve impulses passing through the spine and reaching the thermoregulatory centers in the cerebral cortex. Depending on the nature and strength of the stimulus, excitatory or retention impulses are transmitted to the body's organs and systems. Therefore, water procedures (hot or cold) cause complex reactions, but the perfect system of thermoregulation of the body always keeps the body temperature constant and is one of the most important vital functions of the human body (37°C). The impact of water treatments with warm water leads to the following main physiological results: Active hyperemia (abundant blood flow) to the skin; Active functions of the sweat glands; Activation of metabolism. Regular application of various influences in the aquatic environment contributes to the efficiency of the body's thermo-regulatory systems. Improving thermoregulation means increasing resistance to colds and boosting performance. Thermal regulation is carried out by the processes of heat exchange, expressed by heat reception and heat transfer. These balancing processes maintain the temperature conditions in the body at a constant level. When cooling procedures are applied, the body temperature returns to its original level much faster. When the Spa therapist offers tourists to use water treatments (passive) or physical activity in water (dynamic), it is important to comply with two main categories of rules: psychological and functional. The inclusion of water impacts in tourist packages satisfies two requirements. Firstly, it makes the packages offered more marketable and secondly, along with the functional one, it also has a cosmetic effect. The exact dosage of the effects would lead to a sense of customer satisfaction as a result of which the service will be sought after repeatedly (Table 1).

PSYCHOLOGICAL RULES			
The situation	***Side irritants***	***Positive arguments***	***Price***
Luxurious environment and smart hardware	Music background, individual use of the service, Aroma therapy	Physiological argumentation and examples from the lives of celebrities	High
Hardware equipped middle class	Silence and partitioned perimeter	Tip for the effect of a separate device	Medium/Average
Standard bathtubs and swimming pools	Group use of the procedure	Example with the practice in other countries	Low

Table 1. *Psychological rules for compliance with exposure to water procedures.*

In addition to temperature contrasts, water treatments have a powerful recreational effect through mechanical irritation, which activates the peripheral nervous system. According to the Bulgarian edition of the medical encyclopedia, the skin is an important sensory organ. It contains various mechanoreceptors. They perform tactile sensations, which includes sensations of touch, pressure and vibration. Tactile sensations also include the sensations of stretching the skin, tickling, itching and the movement of an object on the surface of the skin. In addition to tactile sensory, mechanoreceptors can receive information about deep sensory perception (Fig. 2).

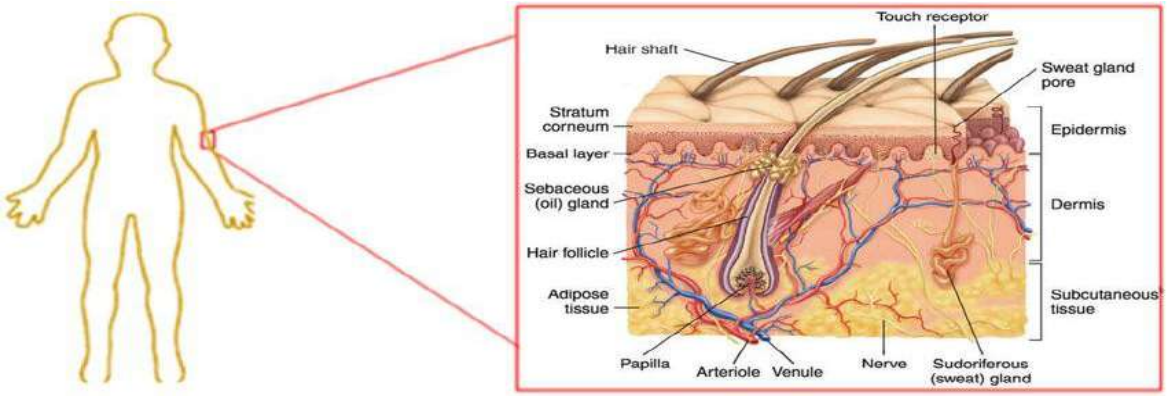


Figure 2. *Three layered skin structures: epidermis, dermis and subcutis (source Eucerin.bg)*

It includes the sensations of movement, strength and direction of movement, muscle tone, position of the body and the movement of its parts in space. In conclusion, the common name mechanoreceptors include touch, pressure and vibration receptors (tactile receptors) and proprioceptors. An important effect is the hydrostatic pressure, which is expressed in a light, evenly distributed massage in the direction of lymphatic and venous outflow from the entire periphery The dosage is determined according to the desired end result of agitation or relaxation. In this regard, the Wellness & Spa consultant needs to consider the body's reactions to exposure to water treatments (Table 2).

Table 2.

Psychological rules for compliance with exposure to water procedures.

PSYCHOLOGICAL RULES			
The situation	***Side irritants***	***Positive arguments***	***Price***
Luxurious environment and smart hardware	Music background, individual use of the service, Aroma therapy	Physiological argumentation and examples from the lives of celebrities	High
Hardware equipped middle class	Silence and partitioned perimeter	Tip for the effect of a separate device	Medium/A verage
Standard bathtubs and swimming pools	Group use of the procedure	Example with the practice in other countries	Low

Recreational water procedures: Water procedures that determine the recreational and cosmetic impact, both during recreation and tourism, and in the daily routine (Fig. 3):

Figure 3. Classification of water procedures with health-preventive or cosmetic applicability.

Water treatments cause reactions to the part of the nervous system. The activity of all other bodily systems is determined by these reactions (Table 3).

Table 3.

System nervous Reactions inside the body during the water procedures.

Nervous system reactions			
T° of water	**Timing**	**Nervous system reaction**	**Muscular tone**
Cold / Warm	1-2 min	Exciting action	Toning effect
Indifferent	20 min	Laxative effect	Eliminates fatigue
Warm / Cool	10 min	Laxative effect	Improves functional capacity
Hot	10 min	Laxative effect	Deeply restores

Warm water, applied for a short time, excites the nervous system, and when applied for a long time, reduces excitatory processes and has a calming effect. Water treatments with indifferent temperature have an optimal effect on the Central Nervous System (CNS). Contrasting intense temperature effects (with hot and cold water) have a pronounced arousing effect on the body of a healthy person

Discussion

We discuss the content and features of basic water procedures that we have applied in practice. The publication describes specific hydrotherapies, while explaining the specifics of their health effects, regarding: Tangentor; Pearl bath; Jet shower; Jacuzzi; Chemically enriched water procedures (drug baths).

Tangentor: The procedure is carried out with the help of a special device (tangentor), which sucks water from the bath by means of a suction pump and returns it back to it under pressure. Underwater massage device is built into the bath, which also has a mounted headrest.

What is the reason for the beneficial effect of underwater shower massage?

The indifferent temperature of the water reduces the tone of the smooth and transversely striated muscles, promotes relaxation, increases the volume of joint movements in their maximum physiological limits. The stimulating effect of the mechanical factor - the water jet, is expressed in elastic vibrations, affecting the tissues in depth. Mechanical irritation caused by relatively high pressure has a pronounced tonic effect - hyperemia occurs quickly.

Pearl bath: The pearl bath is a wonderful water procedure combined with the effect of air bubbles. Pearl baths have a calming effect due to the gentle tactile irritations of the nerve endings eliminate the accumulated nervous fatigue.

Jet shower: This water procedure is a modification of Charko (Шарко). It was introduced for the first time in Bulgaria to Olympic athletes by Dr. V. Mihailova (Olympic finalist).

Jacuzzi The jacuzzi is an integral part of the modern construction of swimming pools in hotel chains. It belongs to the multi-jet baths, but the strength of the underwater jets is significantly weaker than that of the tangentor.

Chemically enriched water treatments (drug baths): To enhance the impact of the water factor, additional chemicals are used - drugs and herbal extracts, essential oils, salts and other chemical mixtures or standard cosmetic additives. They are used in individual water treatments in the bath.

Conclusion

Based on the above analysis of the results and the discussion, we draw the following conclusions: Various water effects have a positive effect on the body's thermo-regulatory abilities; Improving thermoregulation is expressed in increasing resistance to colds; The correct dosage of the effects leads to an emotional feeling of satisfaction on the part of the customers, because of which the service is repeatedly sought; The impact of water treatments with hot water leads to the following main physiological results: active hyperemia (abundant blood flow) to the skin; active functions of the sweat glands; activating metabolism.

Acknowledgement:

Conflict of Interest: *The author and the institution declared no conflict of interest.*

Financial Disclosure: *The article is under the implementation of project BG16RFPR002-1.014-0011 Sustainable Development of the Center of Excellence "Heritage BG," funded under the grant aid procedure BG16RFPR002-1.014 "Sustainable Development of Centres of Excellence and Centres of Competence, Including Specific Infrastructures or Their Associations from the National Roadmap for Scientific Infrastructure".*

Declarations *of informed consent have been signed regarding the publication of survey data.*

ChatGPT is used for English grammar revision and translation.

References

1. Angelcheva, M. (2019). Effects of combination between relax massage and Dr Bach flower remedies on everyday stress. In Proceedings of the International Scientific Congress "Applied Sports Sciences" and Balkan Scientific Congress "Physical Education, Sports, Health" (pp. 348–352). NSA Press.

2. Angelcheva, M., & Petkova, S. (2019). Effects of combination between relax massage and Dr Bach flower remedies on everyday stress. In Proceedings of the International Scientific Congress "Applied Sports Sciences" and Balkan Scientific Congress "Physical Education, Sports, Health" (pp. 348–352). NSA Press.

3. Chipeva, M. (2018). Aerobika: Istoriya, izsledvaniya, obuchenie [Aerobics: History, research and education] [In Bulgarian]. NSA Press.

4. Chipeva, M. (2018a). Aerobno byagane [Aerobic running] [In Bulgarian]. NSA Press.

5. Chipeva, M. (2019). Kango jumps aerobika [In Bulgarian]. Avangard Prima.

6. Dimitrova, N. (2017). The factor motivation for judo training with children. Research in Kinesiology, 45(2), 161–163.

7. Dimitrova, N. (2019). Resistance while managing its own inertial power field. Trakia Journal of Sciences, 17(1), 631–634.

8. Dimitrova, N. (2019a). Reactions of the motor system in local and global activities. Trakia Journal of Sciences, 17(1), 635–637.

9. Dimitrova, N. (2020). Control of the spatial structure in preschool children. Trakia Journal of Sciences, 18(1), 854–856.

10. Dimitrova, N. (2025). Specificity of balance in disposal (weightlifting). German International Journal of Modern Science, 102, 63–66.

11. Dimitrova, N. (2026). Comparative biomechanical analysis of performance against a real target and a "kata" in karate. Trakia Journal of Sciences, 24(2). https://doi.org/10.15547/tjs.2026.02.012

12. Nesheva, I. (2022). Social benefits of wellness motor activities for women with normal pregnancy. Smart Innovations in Recreational, Wellness Industry and Niche Tourism, 4(1–2), 22–27.

13. Nesheva, I. (2023). Pregnancy and wellbeing. Trakia Journal of Sciences, 21(Suppl. 1), 231–235. https://doi.org/10.15547/tjs.2023.s.01.039

14. Nesheva, I. (2023a). A wellness tool to perform healthy lifestyle practices in the Bulgarian school system. Strategies for Policy in Science and Education, 31(5), 560–572. https://doi.org/10.53656/str2023-5-7-wel

15. Polimenov, M. (2014). Innovation in SPA and enology as an opportunity to raise the competitiveness of tourist services. In Proceedings of the International Tourist Forum "SPA and Wine" (p. 163). South-West University "Neofit Rilski".

16. Polimenov, M. (2018). Technological innovations in niche tourism. Smart Innovations in Recreational, Wellness Industry and Niche Tourism, Special Issue, 31–35. https://scjournal.globalwaterhealth.org/

17. Polimenov, M. (2019). Transfer of innovation in service technology for increasing restaurant product quality. Smart Innovations in Recreational, Wellness Industry and Niche Tourism, 1(2), 29–35. https://scjournal.globalwaterhealth.org/

18. Tomova, T., & Angelov, B. (2023). Wellness practices for healthy ageing. Trakia Journal of Sciences, 21(Suppl. 1), 445–450. https://doi.org/10.15547/tjs.2023.s.01.074

19. Tomova, T. (2024). Modeling rituals through combined wellness influences. Smart Innovations in Recreational, Wellness Industry and Niche Tourism, 6(2), 15–24.

20. Tomova, T. (2025). The impact of manual wellness therapies and body massage: A stress relief effect. German International Journal of Modern Science, 105, 23–27.

CUPPING THERAPY: TYPES, FUNDAMENTAL PRINCIPLES, AND EVIDENCE-BASED APPLICATION TECHNIQUES

Tatiana Tomova
Head Ass., Ph.D., Faculty of public health, health care and Tourism
National Sports Academy "Vassil Levski", Sofia, Bulgaria
https://orcid.org/0000-0002-2394-2979
DOI: 10.5281/zenodo.21837673

Abstract

Cupping therapy is one of the oldest complementary therapeutic interventions, with a history spanning several millennia across Traditional Chinese Medicine and other traditional healing systems. This review examines its historical development, principal therapeutic techniques, and contemporary applications in health promotion, disease prevention, and rehabilitation. A narrative review was conducted to analyze the evolution of cupping devices, materials, and application methods, together with the physiological mechanisms associated with negative-pressure stimulation. Current evidence suggests that cupping therapy enhances microcirculation, relieves musculoskeletal pain, promotes tissue recovery, and supports the body's natural healing processes. Owing to its favorable safety profile, low cost, and ease of application, cupping therapy represents a valuable complementary approach within integrative healthcare. However, further well-designed clinical studies are needed to establish standardized treatment protocols and strengthen the evidence supporting its clinical efficacy.

Keywords: cupping therapy; health promotion; preventive healthcare; integrative medicine.

INTRODUCTION

The professional and social dynamics of modern life have contributed to increasingly low levels of physical activity across populations (7, 9). Young people represent the most affected demographic, primarily due to the rapid expansion of information and communication technologies (8, 11). Contributing factors include fast-paced lifestyles, occupational and leisure activities centered on digital and electronic devices, and the growing amount of time spent on social media platforms (3, 10). Another important determinant is the insufficient health culture and the lack of knowledge required to adopt and maintain a healthy lifestyle (4, 12). In some regions, financial constraints and outdated sports infrastructures further discourage participation in regular physical activity (13, 15). Cupping therapy constitutes an important component of Traditional Chinese Medicine (TCM); however, its application has also been documented in numerous cultures worldwide as part of traditional folk medicine (19, 23). Known in Chinese medicine as *bahuoguan liaofa*, cupping therapy has a history spanning several millennia and is recognized as one of the oldest natural therapeutic methods (24). Modern cupping devices are typically small, cup-shaped instruments that create localized negative pressure through either mechanical suction or thermal vacuum. This process induces local hyperemia and congestion by drawing the skin and superficial tissues into the cup. Throughout history, the techniques and styles of cupping therapy have evolved according to geographical location and the materials available in different regions. Animal horns, bamboo, ceramic, glass, metal, and, more recently, plastic have all been used in cupping practice, with the common objective of stimulating the body's intrinsic self-healing mechanisms. Today, cupping therapy is recognized for its broad therapeutic indications, favorable safety profile, cost-effectiveness, and ease of application, making it a widely accessible complementary therapeutic intervention (17, 22). Increasing scientific interest in complementary and integrative medicine has further contributed to its use in pain management, rehabilitation, sports medicine, and preventive healthcare.

METHODS

The aim of the present study was to analyse the most used cupping therapy techniques, examine their historical development, and evaluate their potential applications in treatment, disease prevention, and health promotion. The study employed a narrative literature review, synthesizing historical and contemporary scientific evidence regarding the evolution of cupping therapy, its principal therapeutic methods, and its role within modern complementary medicine, wellness, and preventive healthcare. The analysis focused on the classification of cupping techniques, their mechanisms of application, therapeutic indications, and their contribution to maintaining health and improving quality of life.

RESULTS

We applied a detailed analysis of the Cupping Therapy from Antiquity to the Present. This type of healthy influence is one of the oldest therapeutic modalities in the history of medicine. As an ancient healing practice, it has been applied for thousands of years across numerous civilizations, including China, Greece, Egypt, and the Middle East. In China, cupping therapy has been practiced for more than 2,000 years. Historically, it was known as Jiao Fa (角法) or the "Horn Method", because hollow animal horns were originally used as therapeutic instruments for creating suction (Figures 1 and 2).

Figures 1–2. *Traditional cupping devices made from animal horns.*

Today, this technique is commonly referred to as Huo Guan (火罐) or Fire Cupping. When animal horns were employed, practitioners created negative pressure either by sucking air through a small opening at the tip of the horn, which was subsequently sealed with dried grass, or by heating the horn before application. These procedures were believed to eliminate toxins from the body. Animal horns were also widely used for draining pus from abscesses and treating inflammatory conditions, insect stings, infections, bites, and other localized disorders. Another traditional technique involved heating the horn over burning dry leaves before immediately placing it on the skin to generate suction through thermal expansion and cooling. Chinese practitioners also developed wet cupping, in which superficial skin incisions are made before cup application to facilitate controlled bloodletting. In Western medicine, cupping therapy is believed to have originated in Ancient Egypt. References to cupping have been identified in the Ebers Papyrus, the oldest known Egyptian medical manuscript, dating to approximately 1550 BCE (Fig.3):

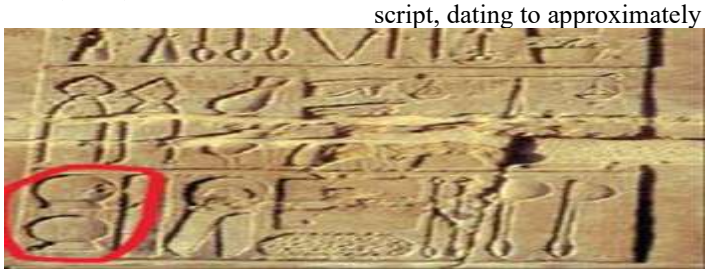


Figure 3. *The Ebers Papyrus, the oldest known ancient Egyptian medical manuscript.*

Historical records further indicate that cupping therapy was incorporated into Ancient Greek medicine, likely through Egyptian medical influence. During the Bronze Age, Greek physicians employed bronze cups for therapeutic purposes, and the technique was later adopted by Roman physicians (Fig.4),

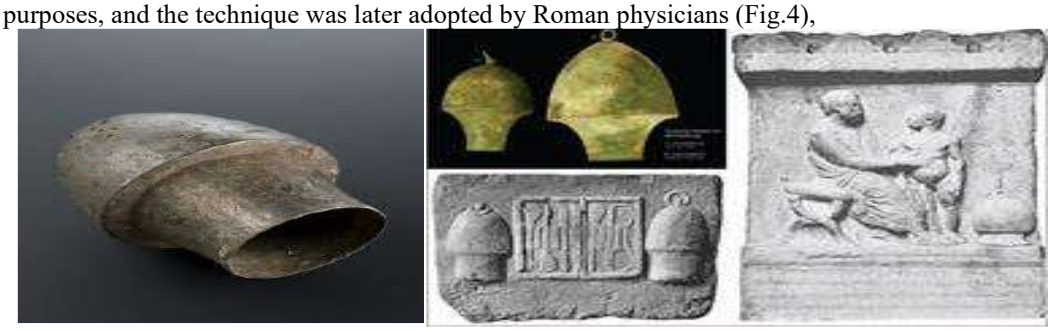


Figure 4. *A cupping instrument used by the ancient Greeks.*

Both Hippocrates and Galen advocated cupping therapy as an effective treatment for a wide range of diseases. The principal therapeutic rationale underlying cupping therapy in antiquity was the removal of harmful substances or the redistribution of blood within the body (16, 22). Ancient Greek physicians employed cupping particularly for the treatment of chronic illnesses and severe pathological conditions (5, 20). Subsequently, cupping therapy spread throughout the Islamic world and Persia via Alexandrian and Byzantine medical traditions. In Islamic medicine, the procedure became known as Hijama, derived from the Arabic word *hajm*, meaning "suction" or "drawing out" (21). Hijama remains one of the principal therapeutic procedures in traditional Islamic medicine and continues to be widely practiced throughout the Middle East. Specialised cupping techniques were also developed to treat gynecological disorders and conditions associated with the female menstrual cycle. Historically, cupping therapy also had spiritual and ritualistic applications. In many cultures, it was believed that the procedure could expel evil spirits responsible for pain, illness, or psychological distress. Over time, animal horns were gradually replaced by bamboo cups, which were heated in boiling water before application to the skin. As the bamboo cooled, negative pressure developed, creating the therapeutic suction effect. This procedure was repeated several times during treatment. Today, cupping devices are manufactured from various materials, including glass, plastic, bamboo, silicone, rubber, and mechanically operated vacuum systems.

Classification of Cupping Therapy Techniques

Contemporary clinical practice recognizes several principal cupping techniques, each differing in its method of application and therapeutic indication.

1. **Static (Retained) Cupping.** The most applied technique, in which cups remain fixed over painful areas or acupuncture points for a predetermined period. Negative pressure is typically created by thermal suc-

tion (fire cupping). It is primarily indicated for musculoskeletal pain, chronic disorders, respiratory diseases, and localized pain syndromes (21, 22).

2. **Moving (Sliding) Cupping.** The skin is lubricated with neutral or herbal oil, allowing the cup to glide over the treatment area until erythema develops. This technique enhances local circulation and is particularly suitable for large muscle groups, including the back, lumbar region, and thighs.

3. **Flash Cupping.** This technique consists of repeated rapid application and removal of the cup, producing intense local hyperemia. It is mainly used for acute musculoskeletal, gastrointestinal, and respiratory disorders.

4. **Warm Water Cupping.** A less frequently used technique in which the cup is partially filled with warm water before application. Due to its technical complexity, it requires considerable clinical experience.

5. **Pulsating Vacuum Cupping.** Modern electronic devices generate rhythmic negative pressure and may be combined with electrotherapy or other physical modalities to enhance therapeutic outcomes.

6. **Combined Acupuncture–Cupping Therapy.** Cupping is applied over previously inserted acupuncture needles after the elicitation of *Qi*. This combined technique is widely used in Traditional Chinese Medicine for localized musculoskeletal disorders and chronic pain syndromes.

7. **Herbal Oil Cupping**. Medicinal oils or herbal tinctures are applied before cup placement to enhance the therapeutic effects of negative-pressure stimulation.

8. **Wet (Bloodletting) Cupping.** Superficial skin punctures are made before cup application to withdraw a controlled amount of blood. This technique has been used in selected dermatological, vascular, neurological, and inflammatory conditions but requires strict aseptic procedures (Lin et al., 2018).

9. Modern Cupping Devices

Glass cups remain the clinical standard because they are inexpensive, easy to sterilize, and allow direct visualization of tissue response, although they are relatively fragile (Fig.5).

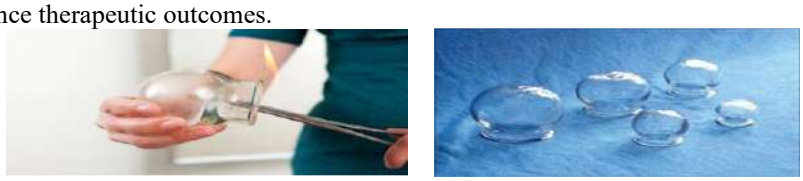


Figure 5. *Classical glass cup used for cupping therapy.*

Plastic cups equipped with manual vacuum pumps eliminate the need for fire and enable precise regulation of suction; some models incorporate therapeutic magnets. Recent technological advances have introduced electronic vacuum cupping systems with adjustable suction and infrared heating, improving muscle relaxation, circulation, lymphatic drainage, and tissue recovery.

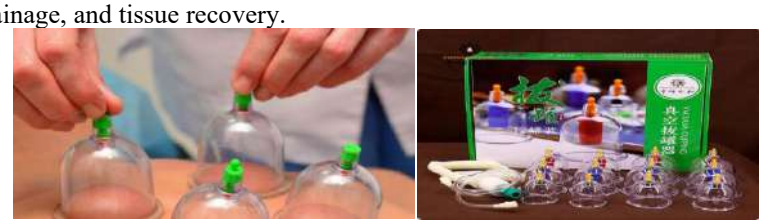


Figure 6. *Plastic cupping cups with magnetic inserts and a hand-operated vacuum pump.*

These innovations have expanded the application of cupping therapy in rehabilitation, physiotherapy, sports medicine, and integrative healthcare (Fig.7).

Figure 7. *Electric Vacuum Cupping Massage Device*

Silicone cups are flexible, easy to use, and particularly suitable for beginners and anatomically challenging areas, although they generate lower suction pressure than conventional cups (Fig.8).

Figure 8. Silicone cups used for cupping therapy.

Bamboo cups, traditionally used in China, are lightweight, inexpensive, and available in various sizes. However, they present limitations related to sterilization, visualization of tissue response, and patient comfort (Fig.9).

Figure 9. Bamboo Cupping Devices

Therapeutic Indications

According to Traditional Chinese Medicine (TCM), cupping therapy promotes the circulation of Qi and blood, disperses pathogenic factors, and alleviates pain and inflammation (20, 21, 22). It is applied both prophylactically to support immune function and therapeutically as an adjunctive intervention for acute and chronic conditions. The primary indications include musculoskeletal pain (neck, shoulder, back, and lower limbs), headaches, respiratory disorders (asthma, bronchitis, chronic cough), gastrointestinal diseases, and selected gynecological conditions. Growing evidence also supports its complementary use in chronic disorders such as hypertension, rheumatoid arthritis, fibromyalgia, diabetes mellitus, migraine, anxiety, depression, varicose veins, cardiovascular diseases, and dermatological conditions, acne or eczema (1, 21).

Therapeutic Effects

The therapeutic effects of cupping therapy are associated with negative-pressure stimulation, which induces local hyperemia, enhances microcirculation, improves tissue oxygenation, and activates neuroendocrine responses. These physiological changes promote pain relief, muscle relaxation, edema reduction, tissue regeneration, and functional recovery (21, 23, 24). Clinical evidence suggests that cupping therapy may improve musculoskeletal function, reduce inflammation and fatigue, stimulate collagen synthesis, enhance skin elasticity, increase joint mobility, and support gastrointestinal and reproductive function. It has also been associated with improved immune response and accelerated recovery following musculoskeletal injuries (2). Although current findings are promising, further randomized controlled trials are required to confirm its efficacy and clarify the underlying biological mechanisms.

Safety Considerations

When performed by appropriately trained practitioners, cupping therapy is considered a safe complementary intervention with a low incidence of adverse effects. Treatment should follow standardized hygienic procedures, including appropriate patient positioning, correct cup selection, and sterilization of reusable equipment, particularly during wet cupping. Common transient reactions include erythema, ecchymosis, and mild blistering, which generally resolve spontaneously. Larger blisters require sterile management to prevent secondary infection. Contraindications include bleeding disorders, open wounds, severe skin disease, deep vein thrombosis, pregnancy over the abdominal and lumbosacral regions, high fever, and application over major blood vessels, the cardiac region, lymph nodes, or mammary glands. Owing to its simplicity, low cost, and favorable safety profile, cupping therapy remains a valuable adjunct to acupuncture, moxibustion, massage therapy, and modern rehabilitation practice.

Common Post-Treatment Reactions

Expected Physiological Responses: The negative pressure generated within the cup typically produces sensations of pulling, tightness, and tissue expansion. Many patients report warmth, relaxation, and immediate symptomatic relief. Following cup removal, localized erythema or characteristic purple-red circular discolorations frequently develop at the treatment sites (Fig. 10). These cutaneous changes represent normal physiological responses and generally resolve spontaneously within several days without medical intervention.

Pathological Reactions

Pathological reactions during cupping therapy may range from mild sensations of tension or burning to severe, intolerable pain. Within several minutes of treatment, blisters, localized edema, or water vapor accumulating inside the cup may develop; these are considered the most common adverse local reactions. According to Traditional Chinese Medicine (TCM), these reactions have diagnostic significance. The appearance of blisters, edema, or clear water vapor is interpreted as an indication of excessive dampness or cold-damp syndrome. Yellowish condensation within the cup is considered indicative of damp-heat syndrome. Red or dark-colored blisters suggest chronic pathological conditions associated with dampness and blood stasis. The characteristic purple discoloration left after cupping is traditionally interpreted as evidence of blood stagnation, whereas a dark purple or black discoloration accompanied by tenderness and fever is considered suggestive of toxin accumulation and severe blood stasis (Fig. 10).

Figure 10. Typical cutaneous markings following cupping therapy

Conversely, the absence of visible tissue changes or local warming during treatment may indicate Qi and blood deficiency. Cutaneous markings accompanied by pruritus are interpreted as evidence of external wind invasion. Pale-colored bruising or bleeding is associated with deficiency syndromes. During combined acupuncture and cupping therapy, dark-red bleeding is regarded as a sign of heat syndrome, whereas bluish discoloration is associated with impaired blood circulation (21). In Traditional Chinese Medicine, these clinical manifestations are interpreted collectively to support differential diagnosis and individualized therapeutic decision-making

DISCUSSION

Adverse Effects

Cupping therapy is generally regarded as a low-risk complementary therapeutic intervention when performed by appropriately trained practitioners. Adverse effects are typically mild, transient, and occur either during treatment or immediately afterward. During the body's adaptive or detoxification response, some patients may experience temporary dizziness, sweating, nausea, fatigue, headache, or generalized muscle soreness. Following treatment, localized skin irritation may occur around the rim of the cup, together with circular ecchymosis, bruising, or pruritus. Uncommon, infection remains a potential complication, particularly following wet cupping procedures. This risk can be minimized through strict adherence to aseptic techniques, appropriate skin preparation, and adequate sterilization of all reusable equipment.

Additional adverse reactions may include:

- thermal burns caused by overheated cups;
- blister formation resulting from excessive suction pressure or prolonged retention of static cups (Fig. 11).

Figure 11*. Blister formation following cupping therapy*

Cupping therapy is contraindicated in patients presenting with active hemorrhage, bleeding disorders or anticoagulant therapy, severe edema, skin irritation (including excessively dry or cracked skin), open wounds, ulcers, varicose veins, deep vein thrombosis, or over blood vessels. Additional contraindications include high fever, convulsive disorders, pregnancy (particularly over the abdominal and lumbosacral regions), and during menstruation when clinically inappropriate. Furthermore, cups should not be applied directly over the cardiac region, lymph nodes, mammary glands, dislocated joints, abscesses, or in patients with severe anemia, muscular dystrophy, or children younger than two years when static cupping is employed (2, 5, 24).

CONCLUSION

Cupping therapy is one of the oldest complementary therapeutic modalities and continues to play an important role in preventive healthcare, rehabilitation, sports medicine, and integrative medicine. Its therapeutic benefits are associated with improved microcirculation, enhanced tissue metabolism, pain reduction, muscle relaxation, and activation of endogenous healing mechanisms, thereby supporting physical recovery and overall well-being.

As a complementary intervention, cupping therapy effectively integrates with acupuncture, moxibustion, massage, and other rehabilitation approaches. The continuous development of new techniques and technologies has expanded its clinical applications, emphasizing the need for standardized professional education, evidence-based practice, and appropriate clinical competencies.

Although cupping therapy has maintained its relevance across centuries and is increasingly accepted in contemporary healthcare, further high-quality clinical research is required to clarify its physiological mechanisms, establish standardized treatment protocols, and strengthen the scientific evidence supporting its efficacy and safety.

Acknowledgement:

Conflict of Interest: *The author and the institution declared no conflict of interest.*

Financial Disclosure: *The article is under the implementation of project BG16RFPR002-1.014-0011 Sustainable Development of the Center of Excellence "Heritage BG," funded under the grant aid procedure BG16RFPR002-1.014 "Sustainable Development of Centres of Excellence and Centres of Competence, Including Specific Infrastructures or Their Associations from the National Roadmap for Scientific Infrastructure".*

Declarations *of informed consent have been signed regarding the publication of survey data.*

ChatGPT is used for English grammar revision and translation.

References

1. Aboushanab, T. S., & AlSanad, S. (2018). Cupping therapy: An overview from a modern medicine perspective.

2. Al-Bedah, A. M. N., Elsubai, I. S., Qureshi, N. A., Aboushanab, T. S., Ali, G. I. M., El-Olemy, A. T., Khalil, M. K. M., Khalil, A. A. H., & Alqaed, M. S. (2018). The medical perspective of cupping therapy: Effects and mechanisms of action. Journal of Traditional and Complementary Medicine, 9(2), 90–97. https://doi.org/10.1016/j.jtcme.2018.03.003

3. Angelcheva, M., & Petkova, S. (2019). Effects of combination between relax massage and Dr Bach flower remedies on everyday stress. In Proceedings of

the International Scientific Congress "Applied Sports Sciences" and Balkan Scientific Congress "Physical Education, Sports, Health" (pp. 348–352). NSA Press.

4. Angelcheva, M. (2019). Effects of combination between relax massage and Dr Bach flower remedies on everyday stress / Mariana Angelcheva, Simona Petkova. // International Scientific Congress "Applied Sports Sciences", Balkan Scientific Congress"Physical Education, Sports, Health" 15-16 November 2019. NSA Press, Sofia, Proceedings: 348-352.

5. Best Health Physio. (2020). Cupping therapy. https://besthealthphysio.ca/cupping-therapy/

6. Dimitrova, B. (2018). Research impact through scientific publications in wellness culture. Avangard Prima.

7. Dimitrova, B. (2019). Quality assessment of standards for wellness services and certified skills of specialised staff. Trakia Journal of Sciences, 17(2), 143–149. https://doi.org/10.15547/tjs.2019.02.007

8. Dimitrova, B., Izov, N., Alexandrova, V., Iosifov, R., & Trendafilov, D. (2021). Smart cognitive toolkit: External assessment of professional competencies for specialised staff in niche tourism [Monograph, in Bulgarian]. NSA Press.

9. Dimitrova, B., & Nesheva, I. (2021a). Research to improve health care for women with normal pregnancy applying recreational wellness activity. Trakia Journal of Sciences, 19(Suppl. 1), 684–690.

10. Dimitrova, B. (2023). Educational policy, specialised staff, innovations and the recreational industry. Strategies for Policy in Science and Education, 31(5), 532–546. https://doi.org/10.53656/str2023-5-6-imp

11. Dimitrova, B., & Tomova, T. (2024). A wellness lifestyle, emotional intelligence, workplace and leadership success. Smart Innovations in Recreational, Wellness Industry and Niche Tourism, 6(2), 51–56.

12. Dimitrova, B. (2025a). Mechanical and energy efficiency in wellness programs with cyclical movements. Series on Biomechanics, 39(1), 59–67. https://doi.org/10.7546/SB.01.08.2025

13. Dimitrova, B. (2025b). Niche tourism: Innovations and quality culture in specialized workforce development. German International Journal of Modern Science, (101), 88–93. https://doi.org/10.5281/zenodo.15124768

14. Dimitrova, B., et al. (2025). Scientific evidence for personalisation of SPA services at the cellular level. German International Journal of Modern Science, (100), 42–46. https://doi.org/10.5281/zenodo.15061591

15. Dimitrova, B. (2026). Assessing the health benefits of forest art therapy: Evidence from Bulgaria. Forestry Ideas, 32(1), 16–18.

16. Healthline. (2020). Cupping therapy. https://www.healthline.com/health/cupping-therapy

17. Huzar, T. (2020). What to know about cupping therapy. Medical News Today. https://www.medicalnewstoday.com/articles/324817

18. International Cupping Association. (2018). History of cupping. http://www.cuppingtherapy.org.in/aboutus/historyof-cupping/

19. Lyme, K. (2018). Cupping Therapy (Hijama). http://www.lyme-kliniek.nl/cupping.html

20. Moore, C. (2018). Cupping vessels for bloodletting. Health Sciences Library, University of Virginia. http://exhibits.hsl.virginia.edu/hist-images/romansurgical/cuppingVessels_e.jpg

21. Nimrouzi, M., Mahbodi, A., Jaladat, A. M., Sadeghfard, A., & Zarshenas, M. M. (2014). Hijamat in traditional Persian medicine: Risks and benefits. Journal of Evidence-Based Complementary & Alternative Medicine, 19(2), 128–136. https://doi.org/10.1177/2156587214524578

22. PT Health. (2020). What is cupping therapy? https://www.pthealth.ca/blog/what-is-cupping-therapy/

23. Tao, X. Y., & Qu, F. (2009). Illustrations of cupping therapy. Shanghai Scientific and Technical Publishers.

24. Xinnong, C. (1987). Chinese acupuncture and moxibustion. Foreign Languages Press.

TECHNICAL SCIENCES

STATISTICAL MODELING OF THE RELATIONSHIP BETWEEN INSTALLED CAPACITY AND EXPORTED POWER: A CASE STUDY FROM THE BANAT REGION

Amariei Olga-Ioana,
Lecturer Ph.D.
Babeș-Bolyai University of Cluj-Napoca, Faculty of Engineering
Square Traian Vuia, no.1-4, 320085, Reșița, Romania
Hamat Codruța-Oana,
Corresponding Author
Professor Ph.D.
Babeș-Bolyai University of Cluj-Napoca, Faculty of Engineering, Romania
Georgevici Gabriela-Felicia,
Lecturer Ph.D.
Babeș-Bolyai University of Cluj-Napoca, Faculty of Sociology and Social Work, Romania
Chicheș Marian
Master's student
Babeș-Bolyai University of Cluj-Napoca, Faculty of Engineering, Romania
DOI: 10.5281/zenodo.21838055

Abstract

This paper extends previous research on the statistical analysis of prosumers connected to the low-voltage distribution network in the Banat region of Romania by evaluating the performance of regression models used to analyze the relationship between installed capacity and exported power. The analysis was conducted using a real-world dataset comprising 21,426 prosumers and included linear, polynomial, and logarithmic regression models. The results indicate that the second-order polynomial regression provides the best balance between estimation accuracy and model complexity, whereas the third-order polynomial regression yields only a marginal improvement in the coefficient of determination. A subsequent segmentation of prosumers according to installed capacity showed that, for installations exceeding 50 kW, the second-order polynomial model achieves superior performance. Finally, two complementary analyses were performed: a residual analysis, which confirmed that the global model adequately describes most observations but exhibits limitations for large-capacity installations, and a one-way analysis of variance (Welch's ANOVA) applied to groups defined by the quartiles of installed capacity. The ANOVA results revealed statistically significant differences among the analyzed groups, which were subsequently confirmed by the Games-Howell post-hoc test. The findings contribute to the development of more accurate statistical models for estimating exported power and may support distribution system operators in the integration, monitoring, and planning of prosumers within smart electricity networks.

Keywords: polynomial regression, linear regression, logarithmic regression, installed capacity, exported power, Welch's ANOVA, Games-Howell post-hoc test.

1. Introduction

The rapid growth in the number of prosumers and the deployment of small- and medium-scale photovoltaic systems represent one of the most significant transformations in modern electricity distribution systems. The integration of an increasing number of photovoltaic installations into low-voltage distribution networks requires the development of statistical methods capable of accurately describing the relationship between installed capacity and the power exported to the grid. In the Banat region of Romania, this growth has been driven by national energy policies and the declining costs of renewable energy technologies, creating the need for detailed analyses of prosumer energy behavior. Furthermore, European Union policies promoting renewable energy have contributed to an 82% reduction in photovoltaic energy costs over the last decade, making solar power one of the most competitive sources of electricity generation within the European Union [3][7].

This paper extends a previous study [1] on the statistical analysis of prosumers connected to the low-voltage distribution network in the Banat region, in which the relationships among the main energy-related indicators were investigated using descriptive statistics as well as simple and multiple linear regression models. The results revealed a very strong correlation between total installed capacity and exported power, together with the high explanatory capability of the linear regression model. However, the findings also suggested the presence of nonlinear behavior in large-capacity photovoltaic installations, thereby motivating the extension of the analysis through the application of polynomial regression models.

The objective of the present study is to evaluate the performance of linear, polynomial, and logarithmic regression models in describing the relationship between total installed capacity and exported power using a real-world dataset comprising 21,426 prosumers from the Banat region. In addition, the study investigates the influence of photovoltaic system size on model performance by segmenting prosumers according to installed

capacity and applying Welch's one-way analysis of variance (ANOVA) to groups defined by the quartiles of installed capacity.

The main contribution of this study lies in the comparative evaluation of several regression models, their validation through residual analysis, and the extension of the statistical assessment by combining sample segmentation with Welch's ANOVA and the Games-Howell post-hoc test. The obtained results provide valuable insights for the development of more accurate forecasting models and may support distribution system operators in the integration, monitoring, and planning of prosumers within smart electricity networks.

2. Data

„The study is based on a dataset obtained from an internal operational database in the Banat region of Romania, containing information on 21,426 prosumers connected to the low-voltage distribution network during the period 2019–2024. The collected data include relevant variables such as total installed capacity, approved power, exported power, active energy produced, active energy consumed, as well as information on the distribution network and electricity meter installation type" [1].

In the present study, the analysis focuses on the relationship between total installed capacity and exported power.

3. Results and Discussion

3.1. Comparative Analysis of Regression Models for the Entire Dataset

To investigate the relationship between installed capacity and exported power, four regression models were employed: linear regression (Fig. 1), second-order polynomial regression (Fig. 2), third-order polynomial regression (Fig. 3), and logarithmic regression (Fig. 4).

The performance of the regression models was evaluated using the coefficient of determination (R^2), which represents the proportion of the variance in the dependent variable explained by the statistical model. Higher values of R^2 indicate a greater explanatory capability and a better overall fit of the model to the observed data.

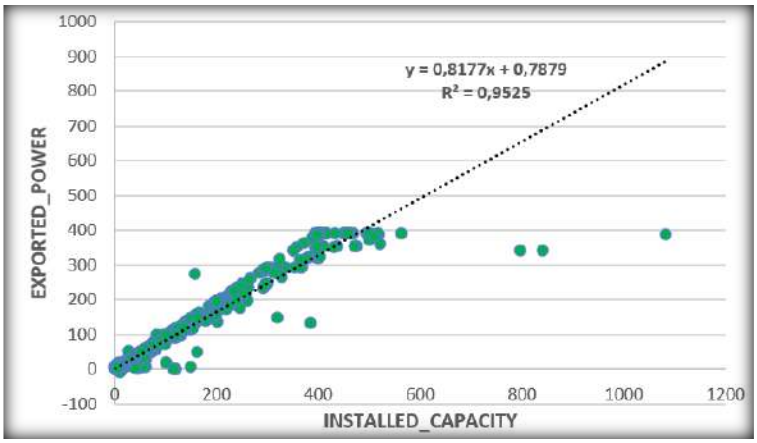


Fig. 1. Linear Regression Model Relating Installed Capacity to Exported Power

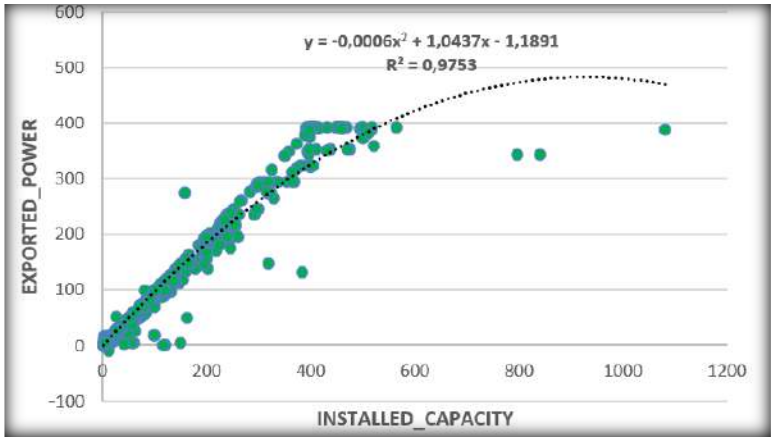


Fig. 2. Second-Order Polynomial Regression Model Relating Installed Capacity to Exported Power

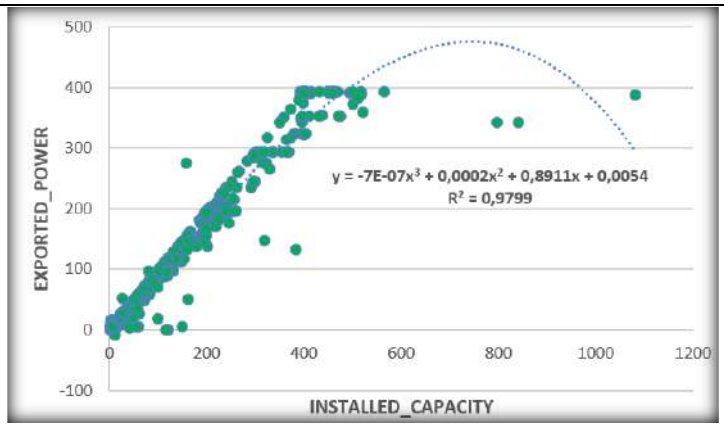


Fig. 3. Third-Order Polynomial Regression Model Relating Installed Capacity to Exported Power

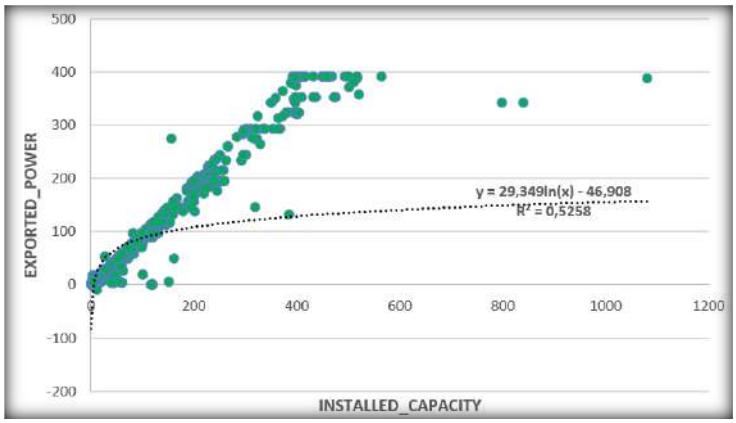


Fig. 4. Logarithmic Regression Model Relating Installed Capacity to Exported Power

As shown in Figures 1–4, the polynomial regression models exhibited a higher explanatory capability, particularly the third-order polynomial model.

Table 1.

Performance of the Regression Models Evaluated for the Entire Dataset

Model	Equation	R^2
Linear	$Y = 0.8177X + 0.7879$	0.9525
Second-Order Polynomial	$Y = -0.0006X^2 + 1.0437X - 1.1891$	0.9753
Third-Order Polynomial	$Y = -7 \times 10^{-7}X^3 + 0.0002X^2 + 0.8911X + 0.0054$	0.9799
Logarithmic	$Y = 29.349\ln(X) - 46.908$	0.5258

Based on the results presented in Table 1, the second-order polynomial regression model was selected to capture the nonlinear nature of the relationship between installed capacity and exported power. The second-order polynomial regression equation is given by:

$$Y = -0.0006xX^2 + 1.0437X - 1.1891 \quad (1)$$

The comparative analysis of the regression models showed that the linear model provides a good fit to the data ($R^2 = 0.9525$); however, the polynomial models significantly improve the explanatory performance. Although the third-order polynomial model achieved the highest coefficient of determination ($R^2 = 0.9799$), it involves greater model complexity while providing only a marginal improvement in predictive accuracy. Therefore, the second-order polynomial regression model was considered the most appropriate, offering the best balance between simplicity and performance.

The logarithmic model exhibited poor explanatory performance ($R^2 = 0.5258$) and was therefore considered unsuitable for describing the analyzed relationship.

3.2. Segmentation of Prosumers According to Installed Capacity

To investigate the influence of photovoltaic system size on the performance of the regression models, the dataset was divided into two categories:

- low-capacity prosumers (installed capacity below 50 kW);
- high-capacity prosumers (installed capacity above 50 kW).

For each category, linear regression (Figs. 5 and 7) and second-order polynomial regression (Figs. 6 and 8) models were developed and compared in order to identify potential nonlinear behavior associated with different installed capacity classes.

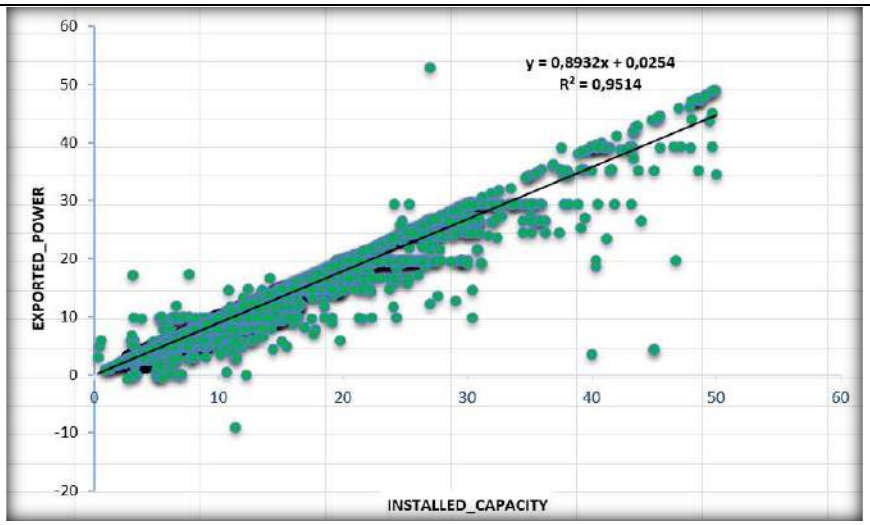


Fig. 5. Linear Regression Model for Low-Capacity Prosumers (<50 kW)

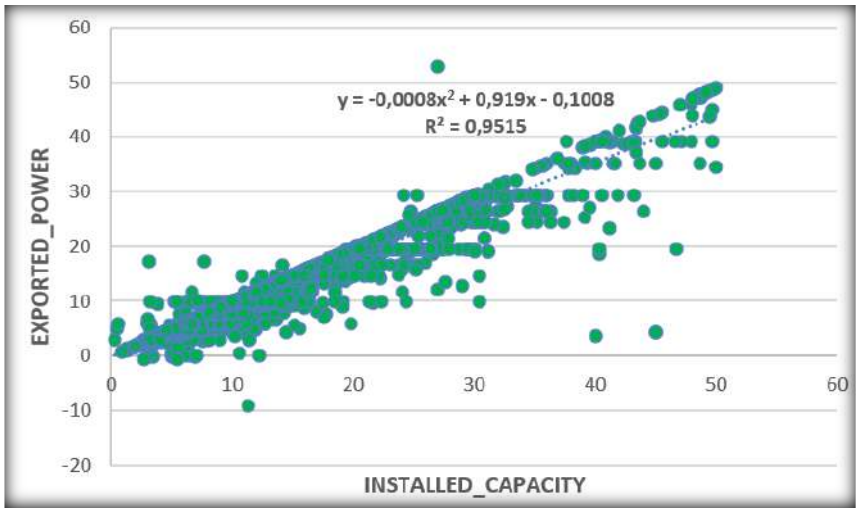


Fig. 6. Second-Order Polynomial Regression Model for Low-Capacity Prosumers (<50 kW)

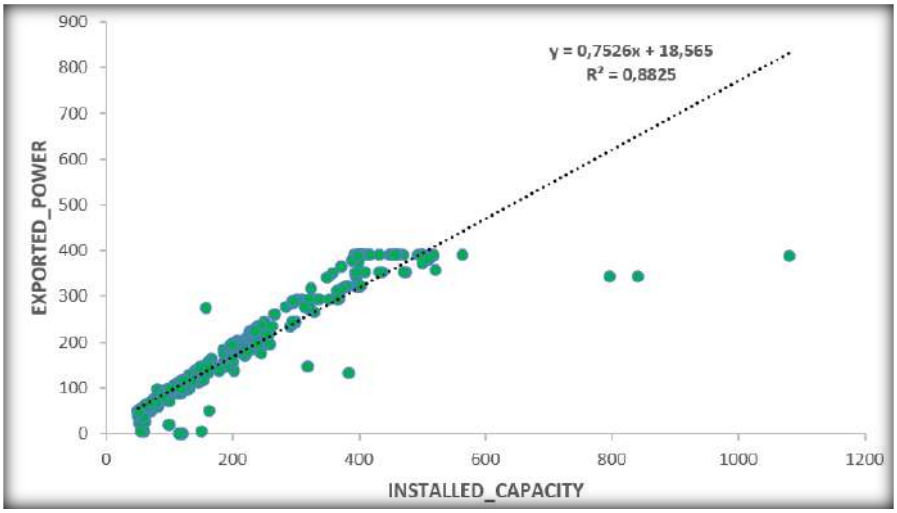


Fig. 7. Linear Regression Model for High-Capacity Prosumers (>50 kW)

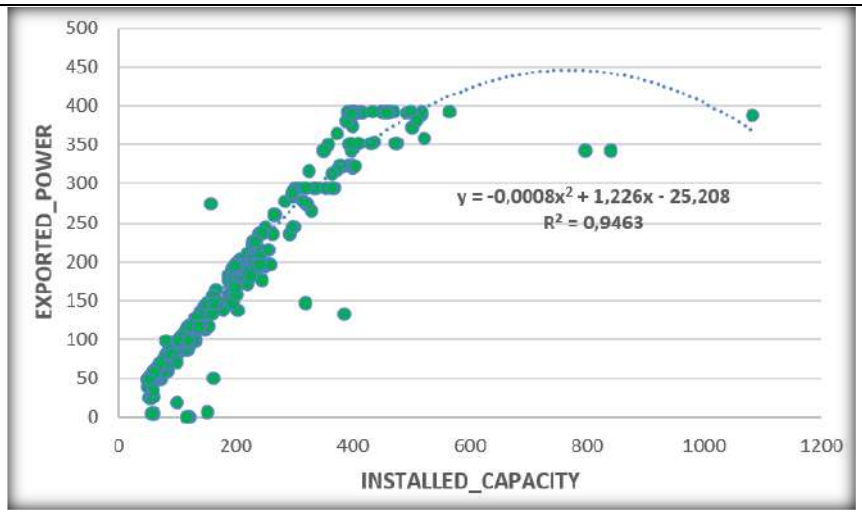


Fig. 8. Second-Order Polynomial Regression Model for High-Capacity Prosumers (>50 kW)

The results presented in Table 2 reveal significant differences between the two categories of prosumers. For systems with an installed capacity below 50 kW, the linear and second-order polynomial regression models exhibit nearly identical performance (R^2 = 0.9514 and R^2 = 0.9515, respectively), indicating a predominantly linear relationship between installed capacity and exported power. In contrast, for prosumers with an installed capacity exceeding 50 kW, the polynomial model substantially improves the explanatory capability of the regression model (R^2 = 0.9463 compared with 0.8825), suggesting the presence of nonlinear effects associated with high-capacity photovoltaic installations.

Table 2.

Performance of the Regression Models for Different Categories of Prosumers

Category	Number of Observations	Model	Equation	R^2
Low-capacity prosumers (<50 kW)	20,850	Linear	$Y = 0.8932X + 0.0254$	0.9514
Low-capacity prosumers (<50 kW)	20,850	Second-Order Polynomial	$Y = -0.0008X^2 + 0.919X - 0.1008$	0.9515
High-capacity prosumers (>50 kW)	576	Linear	$Y = 0.7526X + 18.565$	0.8825
High-capacity prosumers (>50 kW)	576	Second-Order Polynomial	$Y = -0.0008X^2 + 1.226X - 25.208$	0.9463

3.3. Residual Analysis and Model Validation

Following the estimation of the relationship between total installed capacity and exported power using the second-order polynomial regression model, it is necessary to evaluate how well the model represents the observed data. For this purpose, a residual analysis was performed, where residuals were defined as the differences between the observed values of exported power and the corresponding values predicted by the regression model.

Residual analysis constitutes an important step in model validation, as it enables the identification of potential systematic errors, outliers, and variations in model accuracy across the range of the analyzed data.

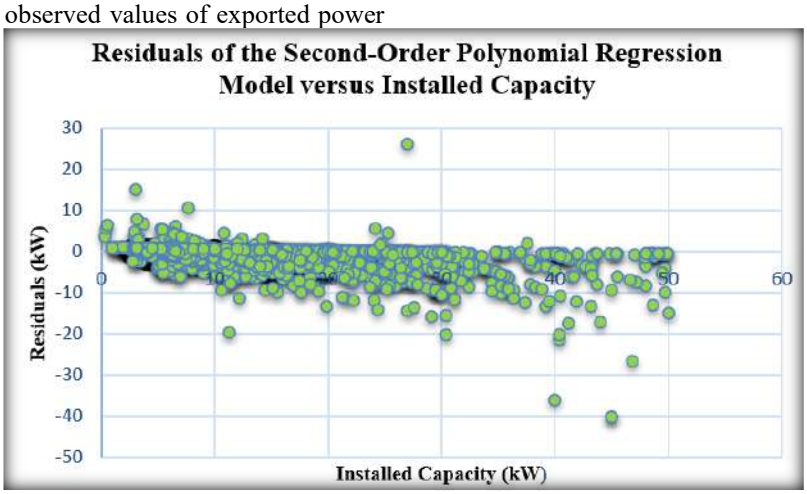


Fig. 9. Residuals of the Second-Order Polynomial Regression Model as a Function of Installed Capacity

The residuals were plotted against total installed capacity (Fig. 9) to examine how the model error varies with increasing system capacity. As shown in the figure, the residuals are concentrated around zero for the majority of installations, indicating that the model provides a good fit to the observed data. However, installations with higher installed capacities exhibit residuals with larger magnitudes, including several outliers, suggesting that the global regression model describes large-capacity photovoltaic installations with lower accuracy than smaller installations.

3.4. Analysis of Variance (ANOVA) by Installed Capacity Groups

In preparation for the analysis of variance (ANOVA), the possibility of segmenting prosumers into installed capacity ranges (0-10 kW, 10-50 kW, 50-100 kW, and above 100 kW), corresponding to technical categories commonly used in photovoltaic systems, was first evaluated. However, this classification resulted in a highly unbalanced distribution of observations, with more than 77% of the prosumers concentrated in the first category, representing small-scale photovoltaic installations typically associated with residential prosumers, while only approximately 2.7% of the observations belonged to the last two categories (Table 3). Consequently, for the statistical analysis, the dataset was segmented according to the quartiles of installed capacity, resulting in four groups of comparable size (Table 4).

Table 3.

Distribution of Prosumers by Installed Capacity Range

Installed Capacity Range	Number of Prosumers	Share (%)
0–10 kW	16,565	77.31
10–50 kW	4,285	20.00
50–100 kW	221	1.03
>100 kW	355	1.66
Total	**21,426**	**100.00**

Table 4.

Segmentation of the Dataset Based on Installed Capacity Quartiles

Group	Installed Capacity Range (kW)	Number of Observations
Q1	0.30 – 5.00	5364
Q2	5.00 – 6.08	5352
Q3	6.08 – 9.475	5353
Q4	9.475 – 1080.97	5357

Before performing the analysis of variance, the assumption of homogeneity of variances was evaluated using Levene's test (Fig. 10). The results indicated a violation of the homogeneity assumption ($p < 0.001$), which justified the use of Welch's one-way ANOVA, recommended when the assumption of equal variances is not satisfied. The results of Welch's ANOVA (Fig. 10) revealed statistically significant differences in the mean exported power among the four groups defined by the quartiles of installed capacity ($F = 12258$, $p < 0.001$).

Fig. 10. Results of Levene's Test for Homogeneity of Variances and Welch's One-Way ANOVA

The descriptive statistics presented in Table 5 indicate a progressive increase in the mean exported power with increasing installed capacity. Furthermore, the fourth quartile exhibits substantially greater variability in exported power than the other groups, indicating that large-capacity photovoltaic installations display more diverse operating behavior.

Table 5.

Descriptive Statistics of Exported Power for the Groups Defined by Installed Capacity Quartiles

Quartile	N	Mean (kW)	Standard Deviation (kW)
Q_1	5,364	3.29	0.698
Q_2	5,352	5.06	0.490
Q_3	5,353	6.32	1.123
Q_4	5,357	28.21	54.873

To identify the pairs of groups that differed significantly, the Games–Howell post-hoc test (Fig. 11) was applied, as it is appropriate when the assumption of homogeneity of variances is violated. The results revealed statistically significant differences between all pairs of quartiles ($p < 0.001$), confirming that exported power increases systematically from lower to higher quartiles of installed capacity.

Post Hoc Tests

Games-Howell Post-Hoc Test – EXPORTED_POWER

		Q1	Q2	Q3	Q4
Q1	Mean difference	—	−1.77	−3.03	−24.9
	p-value	—	< .001	< .001	< .001
Q2	Mean difference		—	−1.26	−23.1
	p-value		—	< .001	< .001
Q3	Mean difference			—	−21.9
	p-value			—	< .001
Q4	Mean difference				—
	p-value				—

Fig. 11. Results of the Games–Howell Post-hoc Test

Figure 12 illustrates a progressive increase in the median values, accompanied by substantially greater variability in the fourth quartile, where numerous outliers corresponding to large-capacity photovoltaic installations can be observed. This increased variability is consistent with the residual analysis presented in Section 3.3 and explains the superior performance of the polynomial regression models for large-capacity photovoltaic installations.

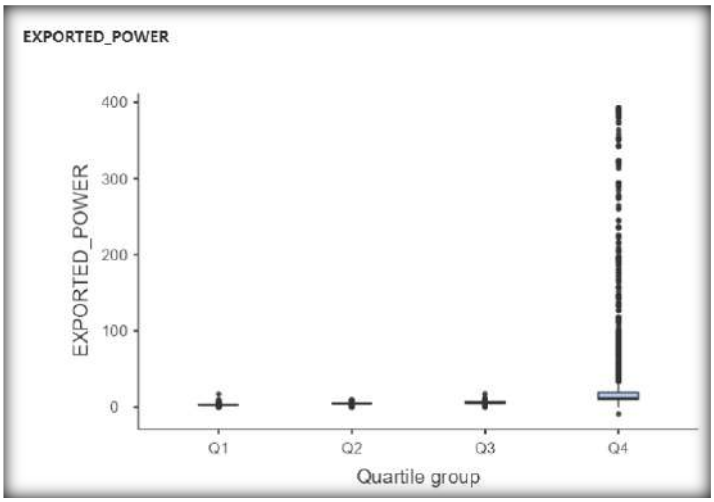


Fig. 12. Distribution of Exported Power According to Installed Capacity Quartiles

4. Conclusions

This study investigated the relationship between total installed capacity and exported power in the low-voltage distribution network using linear, polynomial, and logarithmic regression models based on a real-world dataset comprising 21,426 prosumers from the Banat region of Romania. The comparative analysis showed that the linear model adequately describes the relationship between the two variables ($R^2 = 0.9525$), but polynomial models more accurately capture the behavior of photovoltaic systems than the linear model, particularly for installations with high installed capacities.

Among the models evaluated, the second-order polynomial regression proved to be the most balanced solution, offering the best compromise between estimation accuracy and model complexity. Although the third-order polynomial regression achieved a slightly higher coefficient of determination, the improvement was marginal relative to the increased mathematical complexity. Therefore, the second-order model is considered the most appropriate for forecasting applications.

The segmentation of prosumers according to installed capacity revealed distinct behaviors for the two categories analyzed. For installations with an installed capacity below 50 kW, the linear and polynomial models exhibited similar performance, indicating an almost linear relationship between installed capacity and exported power. In contrast, for installations with an installed capacity exceeding 50 kW, the second-order polynomial regression model significantly improved

the explanatory capability of the regression model, confirming the presence of nonlinear effects associated with large-capacity photovoltaic installations.

The residual analysis confirmed that the polynomial regression model adequately describes most observations while revealing an increase in error variability for high-capacity installations. This finding is further supported by the results of Welch's one-way ANOVA, which demonstrated statistically significant differences among the prosumer groups defined by the quartiles of installed capacity ($p < 0.001$). The Games–Howell post-hoc test confirmed that these differences were statistically significant for all pairwise group comparisons, while the boxplot highlighted the substantially greater variability observed in the fourth quartile.

From a practical perspective, the obtained results may contribute to the development of more accurate statistical models for estimating exported power and support distribution system operators in the integration, monitoring, and planning of prosumers within smart electricity networks. Furthermore, the proposed methodology may be applied to other regions or extended by incorporating additional variables, such as consumer type, the technical characteristics of photovoltaic installations, or meteorological factors, with the aim of developing predictive models with even higher accuracy.

Declaration on the Use of Artificial Intelligence

The authors declare that ChatGPT Plus, developed by OpenAI, was used as an auxiliary tool for structuring, language refinement and translation support. All AI-generated suggestions and translated content were critically reviewed, verified, and approved by the authors. The authors take full responsibility for the final content of the manuscript.

References

1. Amariei O.I, Hamat C.O, Georgevici G., Chicheș M., Statistical Analysis of Prosumers Connected to the Low-Voltage Distribution Network in the Banat Region, Romania, German International Journal of Modern Science, No.132, pp.72-78, DOI: 10.5281/zenodo.21472485, 2026

2. ANRE, Annual Report on the Activity of the Romanian Energy Regulatory Authority, 2024.

3. European Commission, Clean Energy for All Europeans: A New Energy Policy for Europe. European Commission, 2020.

4. Medveď, D., Kolcun, M., Pavlík, M., Beňa, Ľ., & Mešter, M., Analysis of prosumer behavior in the electrical network. Energies, 14(24), 8212, 2021.

5. NIST/SEMATECH, e-Handbook of Statistical Methods. National Institute of Standards and Technology (NIST), 2012.

6. Wei Lu, Jay Wang, Accumulated Performance Comparison of Solar PV and Solar Thermal Water Heating in New Zealand, Engineering Reports, Vol.7, Issue 12, 2025

7. https://eur-lex.europa.eu/legal-content/RO/TXT/?uri=CELEX:52022DC0221

OPTIMIZATION OF DYNAMIC OBSTACLE AVOIDANCE ALGORITHMS FOR AUTONOMOUS MOBILE ROBOTS ON UNEVEN TERRAIN

Ildırımzade Yusif
The student of Cambridge Accredited British Online School, Azerbaijan, Baku
https://orcid.org/0000-0008-3456-6798
DOI: 10.5281/zenodo.21838090

Abstract
The paper studies the solution of the dynamic obstacle avoidance problem of autonomous mobile robots operating in uneven terrain environments. Wheel slip, inclination effect, and increase in kinetic energy on rough surfaces reduce the effectiveness of the traditional Artificial Potential Field (SPS) method, especially when the obstacles move nonlinearly, which leads to the problem of local minimum. To overcome this shortcoming, the parameters of the SPS method (attraction and repulsion coefficients, radius of influence, step coefficient) are optimized using Genetic Algorithm (GA). The kinematic and dynamic model of the robot is extended with an inclination-dependent deceleration function, and a LiDAR/camera-based sensor model is used for real-time detection of dynamic obstacles. Experiments conducted in a series of 10 independent trials in a Python-based simulation environment showed that the proposed SPS-GA method reduced the target arrival time by an average of 31.4%, the trajectory length by 5.63%, and an increase in the energy indicator by 2.25% (the result of moving at speed) compared to the classical SPS method. The success rate for both methods was 10/10. The results show that GA-based optimization is a flexible tool that allows adjusting the speed-energy balance in dynamic environments.

Keywords: autonomous mobile robot, uneven terrain, dynamic obstacle avoidance, artificial potential field method, genetic algorithm, trajectory optimization

INTRODUCTION. In recent decades, the application of autonomous mobile robots has expanded significantly across various fields, including agriculture, construction, search and rescue operations, and planetary exploration. Most of these applications require robots to operate in uneven, sloped, and non-stationary environments, which considerably limits the effectiveness of conventional navigation algorithms. Researchers have reported that traditional path-planning algorithms, such as A*, Dijkstra, and the Dynamic Window Approach (DWA), although widely used in agricultural and other outdoor environments, exhibit limited adaptability under dynamic conditions and on irregular terrain (Fox et al., 1997; LaValle, 2006).

To address these limitations, several hybrid navigation approaches have recently been proposed. For instance, the integration of the Twin Delayed Deep Deterministic Policy Gradient (TD3) reinforcement learning algorithm with DWA enables dynamic adjustment of obstacle evaluation weights and has achieved obstacle avoidance success rates exceeding 90%. However, this approach assumes linear obstacle motion, thereby limiting its applicability in real-world environments characterized by unpredictable obstacle behaviors (Fujimoto et al., 2018). Meanwhile, deep learning-based Transformer architectures, including models employing grouped aggregation strategies, have demonstrated improved semantic perception capabilities in highly dynamic environments. Nevertheless, their high computational complexity and intensive resource requirements reduce their suitability for real-time implementation on resource-constrained robotic platforms (Vaswani et al., 2017). Likewise, sampling-based path-planning methods such as Rapidly-exploring Random Trees (RRT) and their optimized variants (RRT* and RE-RRT*) continue to suffer from slow convergence and considerable computational overhead (Karaman & Frazzoli, 2011).

A review of the existing literature indicates that the majority of previous studies have focused either on flat environments or on scenarios involving static obstacles. Comparatively fewer investigations have simultaneously considered uneven terrain characteristics—such as slope gradients, wheel slip, and varying friction coefficients—together with dynamic obstacle avoidance. Furthermore, although the classical Artificial Potential Field (APF) method remains attractive because of its simplicity and real-time computational efficiency, it is well known for several inherent drawbacks, including susceptibility to local minima and unstable navigation behavior in environments with densely distributed obstacles (Khatib, 1986).

The scientific novelty of this study consists of three principal contributions. First, the parameters of the Artificial Potential Field method are enhanced through the incorporation of a velocity reduction function that explicitly considers terrain slope information. Second, these parameters are automatically optimized using a Genetic Algorithm according to environmental characteristics. Third, the proposed approach is validated through a statistically significant number of repeated simulation experiments using quantitative performance indicators, thereby providing a comprehensive evaluation of its effectiveness for autonomous navigation under dynamic and uneven terrain conditions.

2. Methodology. The state of a differential-drive mobile robot is represented by the vector $q = [x, y, \theta]^T$, where (x, y) denote the coordinates of the robot's center, and θ represents its orientation angle. The kinematic model is expressed as follows (Siciliano et al., 2010):

$$\dot{x} = v \cdot \cos(\theta),\ \dot{y} = v \cdot \sin(\theta),\ \dot{\theta} = \omega$$

where **v** is the linear velocity and **ω** is the angular velocity.

When the robot operates on uneven terrain, the wheel–ground interaction is modeled using a slip coefficient (**σ**). The effective linear velocity is therefore defined as:

$$v\_effektiv = v \cdot (1 - \sigma(\alpha))$$

where **α** denotes the local terrain slope (in radians), and **σ(α)** is the slip function dependent on the terrain inclination. In this study, the relationship is empirically modeled as:

$$v\_ef = v / (1 + k\_s \cdot |\nabla h|)$$

where **h(x,y)** represents the terrain elevation map, **∇h** is its gradient (i.e., the local slope vector), and $\mathbf{k_s}$ is an empirical coefficient determined by the wheel–surface friction characteristics. In the present research, $\mathbf{k_s}$ **= 2.5** was adopted based on experimental observations.

The dynamic model is formulated according to the Newton–Euler equations of motion (Siciliano et al., 2010):

$$M(q) \cdot \ddot{q} + C(q,\dot{q}) \cdot \dot{q} + G(q) = \tau - \tau\_sürüşmə$$

where M(q) denotes the inertia matrix, C(q,\dot{q}) is the centrifugal and Coriolis matrix, G(q) represents the gravitational component induced by terrain inclination, τ is the vector of applied torques, and τ_{slip} denotes the torque loss caused by wheel slip and surface irregularities. The energy consumption during robot motion is evaluated using the following integral:

$$E = \int_0^T (1 + 3 \cdot |\nabla h(x(t),y(t))|) \cdot \|v(t)\|^2 \, dt$$

This formulation accounts for the additional energy required to traverse inclined and uneven terrain. As the terrain gradient increases, greater traction force is required to maintain the desired velocity, leading to higher energy consumption. Consequently, the proposed energy model provides a realistic representation of the robot's power expenditure under off-road operating conditions and serves as an important performance metric in evaluating path-planning algorithms.

Dynamic Obstacle Detection Using LiDAR and Camera

The position and velocity of dynamic obstacles are determined through sensor fusion of a 2D LiDAR scanner (360° field of view, 10 Hz scanning frequency) and an RGB-D camera, which provides depth information. The LiDAR point cloud is segmented into individual objects using Euclidean clustering, while the centroid of each cluster is continuously tracked using a Kalman filter to estimate the obstacle's velocity vector:

$$\hat{x}_k = A \cdot \hat{x}_{k-1} + K_k \cdot (z_k - H \cdot A \cdot \hat{x}_{k-1})$$

where $\hat{x}_k$ denotes the estimated state of the obstacle (position and velocity), A is the state transition matrix, K_k is the Kalman gain, and z_k represents the sensor measurements. The RGB-D camera data are processed using depth-based segmentation to distinguish between static and dynamic objects, enabling the navigation system to focus specifically on moving obstacles while reducing the influence of stationary objects. This sensor fusion approach enhances the reliability and accuracy of obstacle detection in complex and dynamically changing environments, thereby improving the robot's perception capabilities and supporting more robust real-time navigation.

Proposed GA-Optimized Artificial Potential Field (APF-GA) Algorithm

In the classical Artificial Potential Field (APF) method, the total force acting on the mobile robot is expressed as the sum of the attractive force directed toward the target and the repulsive force generated by surrounding obstacles (Khatib, 1986):

$$F = F_{att} + F_{rep},$$

$$F_{att} = k_{att} \cdot \frac{(q_{goal} - q)}{\| q_{goal} - q \|}$$

$$F_{rep} = \sum_i k_{rep} \left(\frac{1}{d_i} - \frac{1}{\rho_0}\right)\left(\frac{1}{d_i^2}\right)\frac{(q - q_i)}{d_i}, \; d_i < \rho_0$$

where k_{att} and k_{rep} denote the attractive and repulsive gain coefficients, respectively; d_i is the distance to the *i*-th obstacle; and ρ_0 represents the obstacle influence radius. One of the major limitations of the conventional APF method is that four key parameters—k_{att}, k_{rep}, ρ_0, and the motion step-size coefficient λ—must be manually tuned according to the operating environment. This manual parameter adjustment increases the algorithm's sensitivity to local minima and reduces its adaptability under varying environmental conditions.

In the proposed approach, these four parameters are automatically optimized using a **Genetic Algorithm (GA)**. Each chromosome is encoded as a real-valued parameter vector:

$$p = [k_{att}, k_{rep}, \rho_0 \lambda].$$

The fitness function is formulated as

$$Fit(p) = w_1 L(p) + w_2 E(p) + w_3 N(p),$$

where $L(p)$ denotes the trajectory length, $E(p)$ represents the energy consumption during robot motion, $N(p)$ is the number of steps required to reach the target, and w_1, w_2, and w_3 are weighting coefficients. In this study, the weighting factors were selected as $w_1 = 1.2$, $w_2 = 0.5$, and $w_3 = 0.03$.

The Genetic Algorithm employs a population of 24 individuals evolved over 30 generations. Parent selection is performed by retaining the best half of the population, followed by arithmetic crossover using a randomly generated coefficient $\alpha \in [0, 1]$:

$$\text{Offspring} = \alpha \cdot \text{Parent}_1 + (1 - \alpha) \cdot \text{Parent}_2.$$

Gaussian mutation is subsequently applied with a probability of 0.3 according to

$$p_i \leftarrow p_i + \mathcal{N}(0, 0.1(b_{max} - b_{min})),$$

where $\mathcal{N}(0, \sigma)$ denotes a Gaussian random variable and b_{max} and b_{min} define the upper and lower parameter bounds, respectively.

During each generation, a complete trajectory simulation is executed for every individual, and the corresponding fitness value is calculated. The best-performing chromosome is preserved through an elitism strategy and transferred directly to the next generation. Consequently, the final output of the proposed algorithm is an optimized parameter set $[k_{att}, k_{rep}, \rho_0 \lambda]$ that is automatically adapted to the terrain characteristics and obstacle distribution of

the operating environment, thereby improving navigation performance and enhancing the robustness of the APF-based path-planning strategy (Khatib, 1986).

RESULTS AND DISCUSSION. The simulation was implemented in the Python 3.11 environment using a NumPy-based numerical computation framework. A synthetic 10 × 10 m uneven terrain map was generated through the superposition of sinusoidal elevation functions and stochastic perturbations to represent realistic terrain irregularities. The simulation environment included five circular dynamic obstacles (radius = 0.5 m) moving with randomly assigned velocity vectors. The starting point was defined at coordinates (2, 2), while the target location was set at (9, 9). To evaluate the robustness and reliability of the proposed method, 10 independent simulation trials were conducted by varying the initial obstacle velocities using ten different random seeds. The optimal parameter values obtained through the Genetic Algorithm (GA) optimization process are presented in Table 1.

Table 1.

Optimal parameters obtained by GA optimization

Attraction coefficient	Repulsion coefficient	ρ₀ (m)	Step coefficient
1.957	1.019	1.255	0.554

The obtained results demonstrate that the proposed APF-GA method significantly improves navigation efficiency in uneven and dynamic environments. Compared with the classical APF algorithm, the proposed approach reduced the average travel time by 31.4%, shortened the path length by 5.63%, and decreased the average number of navigation steps by 28%, while maintaining a 100% success rate in all simulation trials. Although the average energy consumption increased slightly (2.25%), this difference is considered acceptable given the substantial improvements in navigation performance, computational stability, and obstacle avoidance capability. These findings indicate that optimizing APF parameters using a Genetic Algorithm enables more adaptive and reliable path planning under challenging environmental conditions, thereby enhancing the applicability of autonomous mobile robots in real-world outdoor scenarios (Karaman & Frazzoli, 2011).

Comparative Analysis of the Classical APF Method and the Proposed APF-GA Method

The comparative performance of the classical Artificial Potential Field (APF) method (using the commonly recommended parameter values reported in the literature: $k_{att} = 1.0$, $k_{rep} = 3.0$, $\rho_0 = 1.5$, and $\lambda = 0.6$) and the proposed APF-GA method is summarized in Table 2.

Performance Indicator	Classical APF Method	Proposed APF-GA Method	Change (%)
Average travel time (s)	4.14 ± 1.27	2.84 ± 0.25	−31.40
Average path length (m)	11.42 ± 0.83	10.78 ± 0.55	−5.63
Average energy consumption (arbitrary units)	3.00 ± 0.15	3.07 ± 0.12	+2.25
Success rate (10 trials)	10/10	10/10	0
Average number of steps	75	54	−28.00

The results indicate that the proposed APF-GA method reduced the average travel time by 31.40% compared with the classical APF algorithm (baseline: 4.14 ± 1.27 s; optimized: 2.84 ± 0.25 s). Moreover, the standard deviation was reduced by nearly five times, demonstrating a substantial improvement in the stability and consistency of the proposed navigation strategy. The average path length decreased by 5.63%, from 11.42 ± 0.83 m to 10.78 ± 0.55 m, indicating that the optimized algorithm generated more efficient trajectories.

A slight increase of 2.25% was observed in average energy consumption (from 3.00 ± 0.15 to 3.07 ± 0.12 arbitrary units). This increase is consistent with the well-established physical relationship between velocity and energy expenditure, where energy consumption generally increases proportionally to the square of velocity. In this case, the optimization algorithm prioritized faster navigation, thereby achieving significant reductions in travel time at the expense of a marginal increase in energy consumption. Both navigation methods achieved a 100% success rate (10 successful trials out of 10), confirming that each approach is reliable under the selected experimental conditions. However, the proposed APF-GA method demonstrated substantially higher performance while maintaining the same level of reliability.

These findings are consistent with previous studies addressing the trade-off between navigation speed and energy efficiency. Similar observations have been reported for the TD3-DWA hybrid navigation framework, where improvements in obstacle avoidance performance were achieved at the cost of increased computational and energy requirements (Fujimoto et al., 2018). Unlike previous approaches, the proposed method allows users to adjust the weighting coefficients (w_1, w_2, and w_3) to achieve the desired balance among travel time, energy consumption, and path length. Consequently, the proposed framework offers greater flexibility for a wide range of practical applications, including energy-constrained autonomous missions and time-critical search-and-rescue operations.

CONCLUSION

This study proposed an optimized version of the Artificial Potential Field (APF) method based on a Genetic Algorithm (APF-GA) to address the problem of dynamic obstacle avoidance in uneven terrain environments. The robot's kinematic and dynamic model was enhanced by incorporating a terrain-dependent velocity reduction function, while a LiDAR-camera sensor fusion framework combined with a Kalman filter was employed for tracking dynamic obstacles in real time. Statistical analysis based on ten independent simulation trials demonstrated that the proposed method reduced the average travel time by 31.40% and the average path length by 5.63% compared with the classical APF algorithm. Although a slight increase in energy consumption (2.25%) was observed, the proposed method achieved a superior balance between navigation speed, stability, and path efficiency.

Future research will focus on extending the proposed approach to three-dimensional terrain models, coordinated navigation in multi-robot systems, and experimental validation using a real robotic platform operating under ROS 2. Furthermore, replacing the conventional Genetic Algorithm with a hybrid Genetic Algorithm–Particle Swarm Optimization (GA–PSO) framework will be investigated as a promising direction for improving optimization convergence speed and enhancing overall navigation performance.

References

1. Fox, D., Burgard, W., & Thrun, S. (1997). The dynamic window approach to collision avoidance. IEEE Robotics & Automation Magazine, 4(1), 23–33. https://doi.org/10.1109/100.580977

2. Fujimoto, S., van Hoof, H., & Meger, D. (2018). Addressing function approximation error in actor-critic methods. Proceedings of the 35th International Conference on Machine Learning (ICML 2018), 80, 1587–1596. https://proceedings.mlr.press/v80/fujimoto18a.html

3. Karaman, S., & Frazzoli, E. (2011). Sampling-based algorithms for optimal motion planning. The International Journal of Robotics Research, 30(7), 846–894. https://doi.org/10.1177/0278364911406761

4. Khatib, O. (1986). Real-time obstacle avoidance for manipulators and mobile robots. The International Journal of Robotics Research, 5(1), 90–98. https://doi.org/10.1177/027836498600500106

5. LaValle, S. M. (2006). Planning algorithms. Cambridge University Press. https://lavalle.pl/planning/

6. Vaswani, A., Shazeer, N., Parmar, N., Uszkoreit, J., Jones, L., Gomez, A. N., Kaiser, Ł., & Polosukhin, I. (2017). Attention is all you need. Advances in Neural Information Processing Systems, 30, 5998–6008. https://papers.nips.cc/paper/7181-attention-is-all-you-need

7. Siciliano, B., Khatib, O., Groen, F., & Hirose, S. (Eds.). (2010). Springer handbook of robotics. Springer. https://doi.org/10.1007/978-3-540-30301-5

8. Khatib, O. (1986). Real-time obstacle avoidance for manipulators and mobile robots. The International Journal of Robotics Research, 5(1), 90–98. https://doi.org/10.1177/027836498600500106

EVALUATION OF KNOWLEDGE GRAPH INTEGRATION IN LLM-BASED FINANCIAL CHATBOTS

Yernur Demessin,
SDU University
Almaty, Kazakhstan
Darkhan Zholtayev
Supervisor
SDU University
Almaty, Kazakhstan
DOI: 10.5281/zenodo.21838154

Abstract

This study is a comparison of two personal finance chatbot models: LLM only and Knowledge Graph enhanced. They were compared in two criteria: accuracy of answers and response time. The KG was created from the financial transaction dataset. A chatbot architecture consists of two prompts to LLM: the first prompt asks LLM to generate a code that retrieves the context to answer the user's question, and the second prompt queries LLM to frame a response using the context. The chatbots were assessed in accuracy by answering 64 personal finance questions. Results show that the LLM-only chatbot is more accurate than the KG-enhanced chatbot. It is the opposite in response time, the KG-enhanced chatbot is faster than LLM-only chatbot. The research aims to add knowledge to the research field of combining Knowledge Graphs with LLMs and to help practitioners by presenting the benefits and downsides of KG integration.

Keywords: Large Language Models (LLMs), Knowledge Graphs, financial chatbots, personal finance, conversational agents, natural language processing, Neo4j, Cypher, chatbot accuracy, response time, financial transactions, artificial intelligence.

1. Introduction

Since the release of ChatGPT in late 2022, Large Language Models (LLMs) have seen numerous upgrades and adoptions, improving the field of Natural Language Processing (NLP). Due to their ability to maintain the context of conversation, generate reasonable responses, and complete different language-related tasks, LLMs have become a basis of conversational agents, customer service chatbots, educational tutoring tools, and personal finance assistants. Benefits aside, LLM-based applications also have weaknesses, such as the problem of handling domain-specific knowledge and difficulty in maintaining contextual accuracy when responding to complex questions [1]. One way of updating these applications is through the use of external knowledge sources, such as Knowledge Graphs (KGs). KGs can be a way to improve the quality and speed of chatbots' responses.

Chatbots are special programs designed to interact with people in natural language. Older chatbots were rule-based [2]. They worked using these techniques: by asking questions and presenting the user with options to choose, by sending pre-scripted responses to the user if the chatbot encounters specific words or phrases, and by falling back to a general response or by directing the user to a human operator if the chatbot cannot understand the user's question. Newer chatbots are AI-based. They use technologies such as Natural Language Understanding (NLU) and LLM. They make chatbots understand users' intent, maintain conversation context, and generate human-like responses. Chatbots are mainly found in customer service, but they are also used in education, healthcare, and finance. Chatbots can be based on Knowledge Graphs. Knowledge Graphs are a way of representing information that is understandable both by humans and machines. At its base, KG is a triple graph, where vertices represent entities and edges represent relationships between entities [3]. The following paragraphs are a literature review of work related to chatbots.

Research conducted by Nien-Lin and Wei-Che [4] focuses on building a customer service chatbot in the field of the import trade industry. Their proposed chatbot is composed of a Large Language Model (LLM), Retrieval-Augmented Generation (RAG) [5], and Knowledge Graph (KG). Their methodology includes: vectorizing documents, building a domain-specific Question-Answer (QA) dataset, constructing a Knowledge Graph, building a RAG framework, constructing a GPT-based evaluation framework, and creating a set of 101 questions to evaluate the models. Three models: LLM only, LLM with RAG, LLM with RAG and KG were compared with four metrics: number of wins in answering 101 questions, evaluation made by GPT, BLUE, and ROGUE-L. Results of evaluation made by GPT show that LLM with RAG achieved +11.0% higher score than LLM only. LLM with RAG and KG showed +20.7% improvement over the LLM alone model. This trend is consistent across other metrics.

Diploma project submitted by Abhishek and Ishika [6] is centered on building a chatbot based on LLM. They used GPT-3.5 from OpenAI as their LLM model. The interface was made using Gradio. They utilized tools such as StrOutputParser and ChatPromptTemplate. The chatbot was tested using various question-and-answer scenarios to evaluate response quality and context handling.

Neeraj et al. [7] developed an embodied conversational agent that functions as a receptionist for the National Robotarium. The conversational system works on the basis of the Furhat humanoid robot, which can

express emotions. The system begins by recognising the speech and converting it to text, then the system processes and interprets the text, which in turn is sent to GPT-3.5. GPT generates a response alongside the proper emotion for the robot to express. The generated text is converted back to speech, and the robot expresses the emotion. The system also has a database used to retrieve information depending on the user's question.

The result of studying the related literature is a finding that there is only one scientific paper that compares chatbots based only on LLM and one enhanced with KG. This paper aims to aid in filling this research gap.

The purpose of this study is to compare two chatbot models: the first chatbot based on LLM and the second chatbot based on KG. They will be compared by the measures of accuracy of generated responses and response time. The results will be compared against the directly related scientific paper mentioned in the literature review.

Based on the background and literature review results, two hypotheses are created and will be examined in the following research:

H1: The KG-enhanced chatbot will outperform only the LLM-based chatbot in accuracy

H2: The KG-based chatbot will have a shorter response time than the LLM-based chatbot

This study's main contribution is to investigate the effectiveness of enhancing LLM-based personal finance chatbots with Knowledge Graphs. By comparing two models: LLM-based and KG-enhanced, this research adds knowledge to the growing scientific research area of combining structured knowledge representations with LLMs. The results of this study may give insights to researchers and practitioners developing intelligent assistants about the practical benefits and potential downsides of integrating Knowledge Graphs into domain-specific conversational agents.

2. Methods

2.1. Large Language Models

LLMs are deep learning models for text generation. In essence, they work by predicting the next token of the input text. "Large" in the Large Language Model means that the model has a very large number of parameters, usually, from billions to hundreds of billions. LLMs work in the following sequence:

1) Tokenization. Splitting up the input text into tokens. A token is a basic unit of text processed by a language model. A token can be a full word, part of a word, whitespace, punctuation, number, etc.

2) Embedding. It is converting tokens into vectors. Vectors are a set of numbers that represent learned features of the token in a multidimensional space. Tokens that are close in meaning, like "wife" and "husband", have similar vectors. The number of dimensions is very high; for example, GPT 3 has 12,288 dimensions [8].

3) Positional encoding. Structured numerical representation of position of every token is added to the corresponding vector of each token. Because of that, the model knows "dog bites man" is different from "man bites dog", although the tokens are the same.

4) Attention. This is the first step of a two-layer neural network called Transformer, introduced by Google researchers [9].During the process of Attention, every token in the input is related to every other token. As a result of the Attention mechanism, token meanings will be updated by capturing the relations of those tokens to other tokens.

5) Feedforward. Feedforward is the second layer of the Transformer neural network. In this step, every token's meaning is updated on its own. For example, the model understands that a bank is addressed to a financial organization rather than a place near the river. These two layers, Attention and Feedforward, iterate some predefined number of times depending on the model.

6) Softmax and prediction. The prediction vector we got from the Transformer is represented as a set of numbers - logits. But we need to convert these logits into probabilities. To accomplish this task, the vector undergoes a function called softmax. This function makes it so that the vector's numbers are between 0 and 1 and add up to 1. A feature called temperature is added to the model so the model can be random. If the temperature is zero, the model picks the token that has the highest percentage of prediction. Values other than zero add randomness to the output.

2.2. Knowledge Graphs

Knowledge Graphs are a way of representing knowledge in the form of connected graphs. Graphs represent entities, and edges between graphs represent relationships between graphs. Components of the graphs:

- Nodes - the entities in the graph
- Relationships - connections between nodes
- Labels - categories for nodes
- Properties - attributes of nodes and relationships

Figure 1 shows an example of a Knowledge Graph:

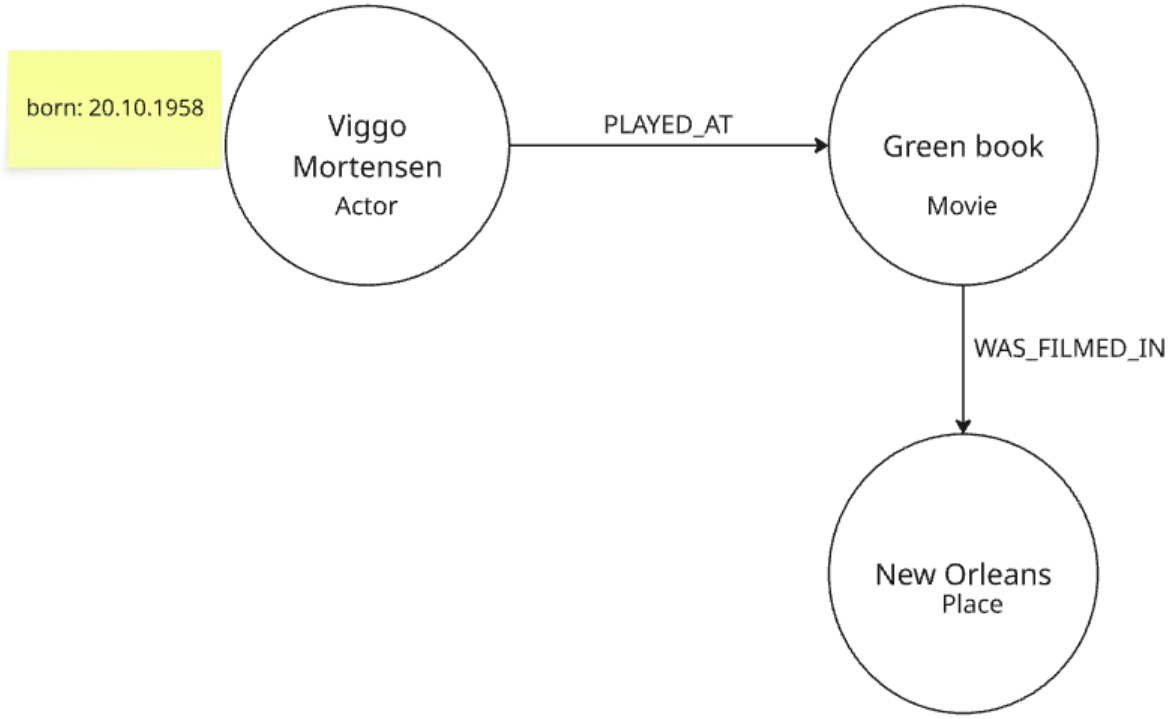


Figure 1. Knowledge graph example

2.3. Dataset

The dataset from which the chatbot retrieves information to answer the user's request is represented by 1385 entries and 8 features. The first feature is "date" - the date on which the transaction occurred. It is in "yyyy-mm-dd" format, and its range spans 6 months from "2022-09-01" to "2023-02-28". The second feature is "account" - anonymized strings of numbers and characters that represent the user's account. There are 4 unique accounts in the dataset. The third feature is "category" - represents a category in which a transaction accrued, for example, "Taxi", "Groceries", "Hobby", etc. There are 32 unique categories in the dataset. The fourth feature is "merchant" - name of the vendor with whom the transaction occurred, for example, "YANDEX TAXI", "002 KFC VAKE", etc. There are 272 unique merchants present. The fifth feature is "transaction_type" - represents a type of transaction relating to the direction, either income or outcome. The sixth feature is "currency" - three capital lettered ISO 4217 currency codes which represent the currency in which the transaction occurred. There are only two unique currencies present in the dataset: Georgian "GEL" and American "USD". The last two features are "amount" and "amount_uc". The first is the amount of money in the original currency of the transaction. The second is the amount of money translated to the user's default currency in the system, with the exact exchange rate present at the time of the transaction. For example, 2.09 USD in the original transaction and 6 GEL in the user's default currency. The dataset was preprocessed by translating "category" and "merchant" values from Russian to English and by replacing nan values with "Not Available" strings.

2.4. Knowledge Graph creation

KG was created using the SQL-like "Cypher" language native to the neo4j database [10]. Account, category, merchant columns were converted to separate labels, while date, currency, amount, amount_uc, and transaction_type become parameters of a label called Transaction. Here is the Cypher query that creates the KG labels and relationships between them:

```
MERGE (a:Account {id: $account})
MERGE (cat:Category {name: $category})
MERGE (m:Merchant {merchant: $merchant})
CREATE (t:Transaction {
   date: date($date),
   currency: $currency,
   amount: $amount,
   amount_uc: $amount_uc,
   type: $transaction_type
})
MERGE (a)-[:MADE_TRANSACTION]->(t)
MERGE (t)-[:IN_CATEGORY]->(cat)
MERGE (t)-[:AT_MERCHANT]->(m)
```

Other than these baseline labels, new labels relating to date and category groups were created. New date labels are: month, quarter, and year. They were related to each other using this Cypher code:

```
MERGE (t)-[:AT_DATE]->(d) # t - Transaction label
MERGE (d)-[:IN_MONTH]->(mo)
MERGE (mo)-[:IN_QUARTER]->(q)
MERGE (q)-[:IN_YEAR]->(y)
```

Categories were divided into groups according to semantic similarity. For example, the Transport category group includes Taxi, Fuel, and Scooter categories, and the Finance category group includes Investments and Debts. Category label is related to category group label using this Cypher code:

```
MERGE (cat)-[:BELONGS_TO]->(cg) # cat - category, cg - category group
```

Figure 2 presents a segment of the created Knowledge Graph:

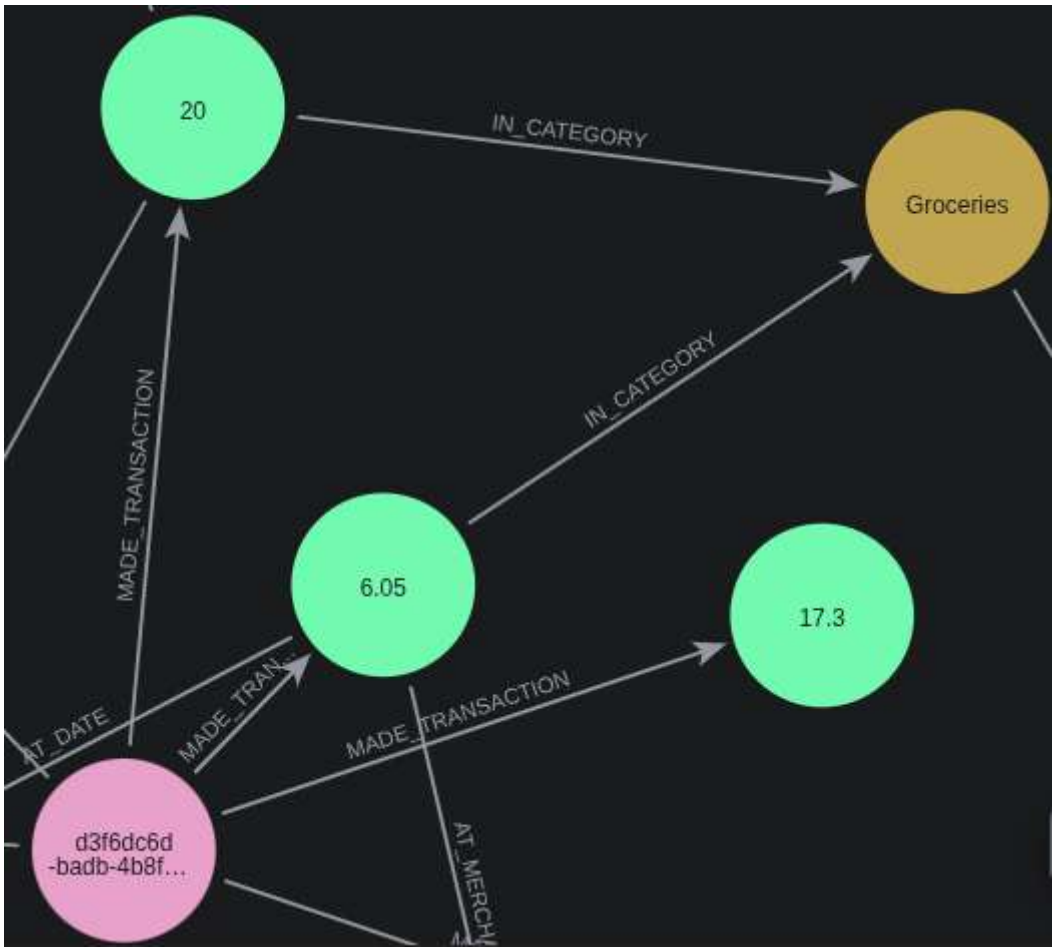


Figure 2. Segment of a Knowledge Graph

2.5. Tools

The code was written in Colab, provided by Google. Colab is a cloud-based version of Jupyter Notebook. It provides an interactive coding environment and access to powerful GPUs. Baseline CPU of Colab was used to run the code. Python 3.12.13 was used as the programming language due to the availability of scientific libraries in it. Claude API provided by Anthropic was utilised as an LLM that powers the chatbot. The exact API model name is claude-sonnet-4-20250514. neo4j Aura is used as an online Knowledge Graph database. Cypher language was used to create and query the KG database. Wandb and its library Weave were used to track the calls to LLM. Pandas was used to import the dataset file. The JSON library was used to convert LLM's output in JSON format to Python's dictionary data type. The time module was used to record the response time of the chatbot.

2.6. Implementation

This research compares two models of chatbots: one with only LLM and one with KG. The first section explains the inner workings of a chatbot with only LLM, and the second section explains the difference between a chatbot with KG and the first chatbot with only LLM.

2.7. LLM only chatbot

From a high-level perspective, the code works through the help of two prompts (queries) to the LLM. The first prompt presents the question to the LLM and asks it to generate the Python code that extracts the answer for the user's query from the dataset.

The first prompt begins by explaining the job that LLM has to do. It follows by describing the fields of transaction dataset, such as the amount of transaction, the date it has accrued, etc. Next, it tells LLM that it will work with a Python class that inherits the parameters of the dataset. The following paragraphs describe the task of generating a Python code that processes a transaction dataset and produces a context to answer the user's question. Context for the questions, such as user account ID, user's language, and default currency is provided in the next section. It is followed by a framework for a context retrieval function that LLM has to fill in. After it, a question for the user is inserted. Followed by format and tone rules for LLM to follow. Finally, output format rules and an example of output are written in the end.

The generated query gets executed and outputs a context needed to answer the user's question. This context is fed to the second prompt, and the LLM is asked to generate a proper response using this context. This second prompt also begins by describing the job. And it is followed by the context and question. Additional information about the user is also provided in the next paragraph. The prompt ends with format and tone rules and a list of 7 questions and answer examples.

Finally, LLM's answer to the second prompt is presented as a final answer to the user's question.

2.8. KG enhanced chatbot

The difference from an LLM-only chatbot is that in the first prompt, the LLM is asked to generate a Cypher query that will answer the user's questions.

The prompt starts with a description of the KG schema, which is needed for LLM to generate a Cypher query. It is followed by the description of the task. Rules and frameworks for writing a Cypher query are written in the next paragraphs. The prompt ends with additional information about the user. Prompt outputs a Cypher query.

The generated Cypher query gets sent to the neo4j Aura online KG database, and the result is fetched. The result of the Cypher query is given to the second prompt as context. And the response of an LLM to the second prompt is presented as a final answer to the user's question.

2.9. Evaluation

Both models were evaluated in terms of the accuracy of responses using 64 questions. The questions are divided into 4 groups: simple retrieval - retrieving one or more facts without using calculations or combining information, aggregation - questions that require summarizing data using mathematical or statistical operations, temporal reasoning - questions that involve dates, time periods, and chronological orders, and multi-category reasoning - questions that require combining information from multiple categories and merchants. Ground truth answers were created alongside the questions. The answers were found and double-checked using SQL. Examples of the questions are given in Table 1.

Table 1.

Information about question set

Category	Number of questions	Question	Expected Answer
Simple retrieval	17	What currencies appear in my transaction history?	GEL
Aggregation	25	How much did I spend on Food delivery?	You spent ₾949.21 on Food delivery
Temporal reasoning	12	During which month did I spend the most on taxi?	You spent the most on taxi in December 2022 with ₾332.1
Multi-category reasoning	10	Compare spending on groceries versus restaurants.	You spent ₾5972.42 on Groceries and ₾4224.93 on Cafes and restaurants. Therefore you spent more on Groceries

The second evaluation metric used is response time. Response time is calculated by using the perf_counter( ) function of the time module. The start of the time counter is placed before a cell where the user's question is chosen, and the end of the counter is placed after the final answer is delivered.

3. Results

The following section presents the results of the research. It is divided into two: Accuracy and Response time.

3.1. Accuracy

Table 2 presents the accuracy of responses provided by chatbots. The accuracies are shown for every 4 categories of questions, and in the end, the overall accuracy is shown. By overall accuracy, the only LLM chatbot is in the lead with 95.31%, while KG enhanced is 82.81%. The best results by category are attributed to the LLM-only chatbot when it answers questions of Simple retrieval and Aggregation with the perfect scores of 100%. And the least result by category is attributed to the KG enhanced chatbot when answering the questions of Multi-category reasoning, with a score of 70%. Interesting to note that the LLM-only chatbot

answered incorrectly to only three of 64 questions, while the KG-enhanced chatbot made 11 mistakes. False responses are divided into two categories: incorrect answers and errors while answering. An error while answering means that LLM responded to the first prompt with the wrong Python or Cypher code, which cannot properly retrieve the context.

Table 2

Response accuracies of chatbots

Category	LLM only chatbot accuracy	KG enhanced chatbot accuracy
Simple retrieval	17/17 (100%)	15/17 (88.24%)
Aggregation	25/25 (100%)	22/25 (88%)
Temporal reasoning	11/12 (91.67%)	9/12 (75%)
Multi-category reasoning	8/10 (80%)	7/10 (70%)
Overall	61/64 (95.31%)	53/64 (82.81%)

3.2. Response time

Table 3 shows the average response times of two chatbots. The table shows response times for every category of questions and the overall response time. From the table, we can see that the KG-enhanced chatbot is faster in every category and in overall response time. It is interesting to note that the average response time of the LLM-only chatbot gradually increases each time the questions get harder, from the first category to last, while KG-enhanced time fluctuates and doesn't correlate with category type. Overall response time of KG enhanced is 7.9737 seconds, and KG enhanced chatbot on average is 60.85% faster than LLM only, which has 12.8254 seconds overall response time.

Table 3Average response time of chatbots

Category	Average LLM only response time (in sec)	Average KG enhanced response time (in sec)
Simple retrieval	11.0963	7.8888
Aggregation	11.7383	7.4576
Temporal reasoning	15.5110	7.8782
Multi-category reasoning	16.4041	9.8215
Overall	12.8254	7.9737

4. Discussion

The LLM-only chatbot showed better accuracy than the KG-enhanced. It can be due to the representation problem: AI systems are usually trained on a vast amount of Python code, whilst Cypher is a niche database knowledge with a significantly smaller footprint in LLMs' pre-training data. It also explains that 4 out of 11 mistakes made by the KG enhanced chatbot are due to wrong cypher code generated by LLM after the first prompt.

When it comes to response time, KG enhanced shows better results by being on average 60.85% faster than LLM only. It can be explained by the fact that Python code has to execute over a full transaction list with 1385 records, while neo4j works by traversing an indexed graph.

By analysing the results, we can conclude that the H1 hypothesis, which stated that the KG-enhanced chatbot will be better at accuracy than LLM only, turned out to be false. But the H2 hypothesis correctly predicted that the KG-enhanced chatbot would outperform the LLM-only chatbot in response time.

Results of this research can be compared with the findings of a study done by Nien-Lin and Wei-Che. But the comparison is not exact, because they compare LLM only with the KG+RAG, while this research compares LLM only with KG enhanced (without RAG). The second factor is that their LLM only model relies on its internal pre-trained memory, while our bot generates code that executes over an external dataset. By their result, KG+RAG outperforms LLM-only, while the findings of this research state that the LLM-only chatbot is better at the accuracy of responses than the KG-enhanced chatbot. But the LLM only loses to KG enhanced in terms of response time, which is not covered in the referenced study. This can be explained by the difference in domains: this paper utilizes a financial transaction chatbot whose data source is in tabular form, while the referenced paper builds a chatbot for the import trade domain, and its data is textual, where explicit knowledge graphs excel.

Two primary limitations of the research are: human evaluation and a static dataset. Accuracy was assessed through human judgment, and it may introduce subjectivity. Chatbot is static, and it works with the fixed transaction dataset, while real-world applications need dynamic memory: new entries have to be added, updated, and removed while the application is working.

5. Conclusion

This research compared two models of chatbot: LLM only and KG enhanced. They were evaluated in domains of accuracy and response time. The LLM-only chatbot showed better accuracy, and KG-enhanced responses were faster in response time. Future research can investigate the creation of a chatbot with real-time memory. Another idea is evaluating the combination of KG and RAG. Applying this chatbot framework to other domains than financial transactions can also be explored.

References

1. Z. Ji, N. Lee, R. Frieske, T. Yu, D. Su, Y. Xu, E. Ishii, Y. J. Bang, A. Madotto, and P. Fung, "Survey of Hallucination in Natural Language Generation," ACM Computing Surveys, vol. 55, no. 12, pp. 1–38, 2023.

2. E. Adamopoulou and L. Moussiades, "An Overview of Chatbot Technology," in IFIP International Conference on Artificial Intelligence Applications and Innovations (AIAI), Springer, 2020, pp. 373–383.

3. Hogan, E. Blomqvist, M. Cochez, C. d'Amato, G. de Melo, C. Gutierrez, S. Kirrane, J. E. L. Gayo, R. Navigli, S. Neumaier, A.-C. Ngonga Ngomo, A. Polleres, S. M. Rashid, A. Rula, L. Schmelzeisen, J. Sequeda, S. Staab, and A. Zimmermann, "Knowledge Graphs," ACM Computing Surveys, vol. 54, no. 4, pp. 1–37, 2021.

4. N. Hsueh, W. Lin, “Design of a RAG-Based Customer Service Chatbot Enhanced with Knowledge Graph and GPT Evaluation: A Case Study in the Import Trade Industry”, vol. 5, no. 2, Art. no. 15, 2026.

5. P. Lewis, E. Perez, A. Piktus, F. Petroni, V. Karpukhin, N. Goyal, H. Küttler, M. Lewis, W. Yih, T. Rocktäschel, S. Riedel, and D. Kiela, "Retrieval-Augmented Generation for Knowledge-Intensive NLP Tasks," Advances in Neural Information Processing Systems, vol. 33, pp. 9459–9474, 2020.

6. Abhishek and I. Goswami, "Building an AI Chatbot Using LLM," B.Tech. major project report, Dept. Comput. Sci. Eng. Inf. Technol., Jaypee Univ. Inf. Technol., Waknaghat, Solan, India, 2024. [Online].Available:http://www.ir.juit.ac.in:8080/jspui/bitstream/123456789/11451/1/Building%20and%20AI%20Chatbot%20using%20LLM.pdf

7. N. Cherakara, F. Varghese, S. Shabana, N. Nelson, A. Karukayil, R. Kulothungan, M. A. Farhan, B. Nesset, M. Moujahid, T. Dinkar, V. Rieser, and O. Lemon, "FurChat: An Embodied Conversational Agent Using LLMs, Combining Open and Closed-Domain Dialogue with Facial Expressions," in Proceedings of the 24th Annual Meeting of the Special Interest Group on Discourse and Dialogue (SIGDIAL), Prague, Czechia, 2023, pp. 588–592.

8. T. Brown, B. Mann, N. Ryder, M. Subbiah, J. D. Kaplan, P. Dhariwal, A. Neelakantan, P. Shyam, G. Sastry, A. Askell, et al., "Language Models are Few-Shot Learners," Advances in Neural Information Processing Systems, vol. 33, pp. 1877–1901, 2020.

9. Vaswani, N. Shazeer, N. Parmar, J. Uszkoreit, L. Jones, A. N. Gomez, Ł. Kaiser, and I. Polosukhin, "Attention Is All You Need," in Advances in Neural Information Processing Systems (NeurIPS), vol. 30, 2017.

10. N. Francis, A. Green, P. Guagliardo, L. Libkin, T. Lindaaker, V. Marsault, S. Plantikow, M. Rydberg, P. Selmer, and A. Taylor, "Cypher: An Evolving Query Language for Property Graphs," in Proceedings of the 2018 ACM SIGMOD International Conference on Management of Data, 2018, pp. 1433–1445.

VETERINARY SCIENCES

PCR-BASED DETECTION OF AUJESZKY'S DISEASE VIRUS (SUID ALPHAHERPESVIRUS 1) USING EVAGREEN REAL-TIME PCR ASSAY

Gerilovych A.[1, 2],
ORCID: 0000-0002-3280-4172
Korovin I.[1, 3],
Vashchyk Ye.[3, 4]
ORCID ID: 0000-0002-5980-6290
[1]*PSI One Health Scientific and Research Institute, Kharkiv, Ukraine*
[2]*Institute for Problems of Cryobiology and Cryomedicine of NAS of Ukraine, Kharkiv, Ukraine*
[3]*National Scientific Center Institute for Experimental and Clinical Veterinary Medicine, Kharkiv, Ukraine,*
[4]*State Biotechnological University, Kharkiv, Ukraine*
DOI: 10.5281/zenodo.21838217

Abstract

Aujeszky's disease virus (ADV) poses significant economic and animal health challenges in swine populations. Rapid, sensitive, and specific detection methods are essential for early diagnosis and effective disease control.

Study was aimed to develop and validate a real-time PCR assay using EvaGreen chemistry on the iTOWER platform for the detection of the ADV gE gene, evaluating its analytical performance, specificity, reproducibility, and diagnostic sensitivity compared to conventional methods.

The assay was tested on clinical samples from 30 swine, with amplification performance assessed through sigmoidal fluorescence curves and melting curve analysis. Analytical sensitivity, limit of detection (LOD), amplification efficiency, linearity (R^2), and reproducibility were evaluated using serial dilutions of ADV DNA. Specificity was confirmed using heterologous viral DNA, and diagnostic performance was compared with allergic testing and virus neutralization assays.

The developed qPCR assay reliably detected ADV DNA in all clinically positive samples and identified an additional low-viral-load case missed by virus neutralization. Ct values ranged from 18.4 to 33.2, with high reproducibility (coefficient of variation <2%). Melting curve analysis confirmed amplification specificity, with single peaks corresponding to the 235 bp gE amplicon. Analytical sensitivity reached 10^2 genome copies per reaction, with optimal amplification efficiency (100%) and strong linearity ($R^2 = 0.998$) across a five-log dynamic range. No cross-reactivity was observed with non-target herpesviruses.

The EvaGreen-based qPCR assay provides a rapid, sensitive, and specific tool for the detection of ADV, suitable for both diagnostic and epidemiological applications. Its integration into One Health surveillance frameworks can enhance early detection and support disease management in swine populations.

Keywords: Aujeszky's disease virus; EvaGreen qPCR; iTOWER; diagnostic sensitivity; viral detection; One Health; swine health; gE gene

Introduction

The One Health concept recognizes the interconnectedness of human, animal, and environmental health and emphasizes the need for integrated approaches to disease surveillance and control (Centers for Disease Control and Prevention [CDC], 2022). Within this framework, the monitoring of transboundary and zoonotic pathogens in animal populations is essential for safeguarding both animal health and public health systems. Among such pathogens, Aujeszky's disease virus (ADV), also known as Suid alphaherpesvirus 1, remains a significant concern for the global swine industry due to its high transmissibility, broad host range, and substantial economic impact.

Aujeszky's disease (AD) is characterized by neurological, respiratory, and reproductive disorders in swine, with particularly severe outcomes in young animals (Pomeranz et al., 2005). Although eradication programs have been successfully implemented in several countries, the virus continues to circulate in wild boar populations and in regions with insufficient biosecurity measures, posing a constant risk of reintroduction into domestic herds (Müller et al., 2011). The persistence of ADV in latent form further complicates disease control, necessitating highly sensitive diagnostic tools capable of detecting low viral loads.

Conventional diagnostic methods, including virus isolation, virus neutralization tests, and enzyme-linked immunosorbent assays (ELISA), are widely used but have notable limitations. These techniques are often time-consuming, labor-intensive, and may lack sensitivity during early or latent stages of infection (OIE, 2021). Molecular methods, particularly polymerase chain reaction (PCR)-based assays, have therefore become the gold standard for rapid and sensitive detection of viral pathogens.

Real-time PCR (qPCR) technologies provide significant advantages over conventional PCR, including increased sensitivity, specificity, and the ability to monitor amplification in real time without post-PCR processing (Mackay et al., 2002). The use of intercalating dyes such as EvaGreen offers a cost-effective and reliable alternative to probe-based systems while main-

taining high analytical performance and enabling melting curve analysis for product verification (Mao et al., 2007). These features are particularly valuable in routine veterinary diagnostics and large-scale surveillance programs.

Targeting viral glycoprotein genes, such as gE, is a well-established strategy for ADV detection and differentiation between infected and vaccinated animals (DIVA strategy), further enhancing the epidemiological value of molecular diagnostics (Mettenleiter, 2000). Despite the availability of various PCR protocols, there remains a need for optimized, reproducible, and cost-effective assays adaptable to modern real-time PCR platforms.

Therefore, the aim of this study was to develop and validate a real-time PCR assay based on EvaGreen chemistry using the iTOWER platform (Jena Analytik) for the detection of ADV DNA targeting the gE gene. The proposed method is intended to improve diagnostic efficiency and support integrated disease monitoring within the One Health framework.

Materials and Methods. This study was designed to develop and validate a real-time polymerase chain reaction (qPCR) assay for the detection of Aujeszky's disease virus (ADV) DNA in biological samples from swine. The analytical performance of the assay, including sensitivity, specificity, and reproducibility, was evaluated in comparison with conventional diagnostic methods.

Biological samples. A total of 45 samples were included in the study: 30 blood samples obtained from pigs (15 previously identified as ADV-positive and 15 as ADV-negative based on routine diagnostic tests); 10 clinical samples (internal organs and mucosal swabs) collected from animals with suspected ADV infection; 5 samples from clinically healthy animals used as negative controls.

Blood samples were stabilized using sodium citrate or glucose solution and stored at 4°C prior to analysis. Tissue samples and swabs were transported under refrigerated conditions and processed within 24 hours.

DNA extraction. Total DNA was extracted using magnetic beads-based commercial kits MagnetPureDNA/RNA, IBT, Ukraineaccording to the manufacturer's instructions. Procedure included lysis of biological material in a chaotropic buffer; adsorption of nucleic acids onto sorbent; sequential washing steps to remove contaminants; elution of purified DNA in TE buffer.

Extracted DNA was stored at −20°C until further analysis. DNA concentration and purity were not additionally normalized, as the assay was optimized for direct use of eluates.

Real-Time PCR (qPCR) assay. The assay targets the glycoprotein E (gE) gene of ADV. The following primers were used (Gerilovych, 2011):

AuDV_gE_F: 5′-TCG GCC CTC GCC TCC CTG A-3′

AuDV_gE_R: 5′-TGC CCA TCT CCG GGG CCT C-3′

The expected amplicon size is 235 base pairs.

Real-time PCR was performed in a final volume of 20 µL containing:

- 10.0 µL 2× EvaGreen qPCR Master Mix;
- 0.5 µL forward primer (10 µM);
- 0.5 µL reverse primer (10 µM);
- 2.0 µL DNA template;
- 7.0 µL nuclease-free water.

All reactions were prepared on ice to minimize nonspecific amplification.

Amplification was performed using the iTOWER real-time PCR system (Jena Analytik, Germany) under the following conditions:

Initial denaturation: 95°C for 3 min;

40 cycles of:

- denaturation: 95°C for 10 s;
- annealing/extension: 58°C for 30 s (fluorescence acquisition step).

Fluorescence was measured at the end of each annealing/extension step.

Melting Curve Analysis. To verify amplification specificity, a melting curve analysis was performed immediately after PCR: temperature range: 65°C to 95°C with increment: 0.2–0.5°C with continuous fluorescence acquisition. Specific amplification of the target fragment was confirmed by the presence of a single, distinct melting peak at the expected melting temperature (Tm).

Controls and quality assurance

Each qPCR run included the following controls: positive control: DNA extracted from inactivated ADV culture; negative control: nuclease-free water;

No-template control (NTC): to monitor contamination during reaction setup.

At least three negative controls were included per run. Any amplification observed in negative controls resulted in rejection and repetition of the assay.

Interpretation of results. Results were analyzed using the iTOWER system software.

Samples were considered positive if amplification curves were detected with a threshold cycle (Ct) value < 35 and a specific melting peak was observed. They were considered negative if no amplification curve was detected or $Ct \geq 35$;

Invalid results were in case if amplification was observed in negative controls or if melting curve analysis indicated nonspecific products.

Analytical sensitivity and specificity

Sensitivity was evaluated by testing known ADV-positive samples and comparing results with virus neutralization assays.

Interspespecies specificity was assessed using DNA samples from turkey herpesvirus; Marek's disease virus; bovine herpesvirus type 1 (infectious bovine rhinotracheitis virus).

Reproducibility. All samples were tested in triplicate across independent runs. Reproducibility was assessed based on variation in Ct values and consistency of melting profiles.

Statistical analysis. Descriptive statistics were used to summarize results. Diagnostic performance was evaluated by comparing detection rates between qPCR and conventional methods. Reproducibility was assessed by calculating variation in Ct values (mean ± standard deviation).

Results. The developed EvaGreen-based real-time PCR assay enabled reliable detection of Aujeszky's disease virus (ADV) DNA in all tested samples. Amplification curves obtained using the iTOWER real-time PCR system demonstrated typical sigmoidal kinetics, with a clear exponential phase followed by a plateau, confirming efficient amplification. Positive samples exhibited strong fluorescence signals crossing the threshold within 18.4–33.2 cycles depending on viral load, whereas no amplification was observed in negative samples or no-template controls, indicating absence of contamination and high analytical specificity.

Diagnostic performance and comparative analysis. Comparative evaluation of diagnostic performance revealed that the qPCR assay demonstrated higher sensitivity than conventional methods. Among 15 animals previously identified as positive, the assay detected ADV DNA in all cases and additionally identified one sample that was negative by virus neutralization. In contrast, virus neutralization detected only 12 positive samples. The allergic test showed full agreement with clinical classification; however, it does not directly detect viral DNA and therefore cannot distinguish active infection from prior exposure. These findings indicate that the developed qPCR assay is capable of detecting low viral loads that may not be identified by traditional serological methods.

Table 1 shows that the EvaGreen-based qPCR assay detected one additional positive sample compared to virus neutralization, demonstrating its higher analytical sensitivity. The allergic test reflected clinical status but does not measure viral DNA directly.

Table 1

Comparative diagnostic results for ADV detection

Method	Positive animals (n=15)	Negative animals (n=15)
Allergic test	15	15
Virus neutralization	12	18
qPCR (EvaGreen, iTOWER)	16	14

Cycle threshold (Ct) values. Quantitative analysis of amplification data demonstrated consistent cycle threshold (Ct) values across replicate measurements. Samples with high viral load were characterized by Ct values below 22, whereas moderate and low viral loads corresponded to Ct ranges of 22–28 and 28–33, respectively. The low variability of Ct values between replicates (standard deviation not exceeding 0.5 cycles) confirms the high reproducibility and precision of the assay.

Table 2 illustrates that lower Ct values correspond to higher viral loads, while higher Ct values indicate lower viral concentrations. The narrow standard deviation demonstrates excellent reproducibility of the assay.

Table 2

Distribution of Ct values in ADV-positive samples

Sample group	Ct range	Mean Ct ± SD
High viral load	18.4–22.0	20.1 ± 1.2
Moderate viral load	22.1–28.0	25.3 ± 1.8
Low viral load	28.1–33.2	30.4 ± 1.5

Specificity of the assay

Specificity testing using heterologous viral DNA samples, including turkey herpesvirus, Marek's disease virus, and bovine herpesvirus type 1, did not produce any detectable amplification signals. Only samples containing ADV DNA yielded positive results, confirming that the assay is highly specific to the target pathogen and does not cross-react with related herpesviruses. It was confirmed that the assay selectively amplifies the ADV gE gene and does not cross-react with other related viruses, highlighting its high specificity (Table 3).

Table 3

Specificity testing against non-target viruses

Virus tested	Amplification result
Aujeszky's disease virus (ADV)	Positive
Turkey herpesvirus	Negative
Marek's disease virus	Negative
Bovine herpesvirus type 1	Negative

Reproducibility of the assay. The assay demonstrated high reproducibility across replicates and independent runs, with low variation in Ct values. Table 4 indicates that the coefficient of variation remained below 2% for all samples, demonstrating high precision and repeatability of the qPCR assay.

Table 4

Reproducibility of qPCR results (Ct variation)

Sample ID	Mean Ct	SD	Coefficient of variation (%)
S1	21.3	0.4	1.88
S2	25.7	0.5	1.95
S3	30.1	0.6	1.99

Melting curve analysis revealed a single, sharp peak for all positive samples at approximately 83°C, corresponding to the expected 235 bp amplicon of the gE gene. No secondary peaks or shoulders were observed, indicating absence of primer-dimers and non-specific amplification. Negative controls did not produce detectable melting peaks, further validating assay specificity.

Analytical sensitivity, standard curve, and quantitative performance. The analytical sensitivity of the assay was determined using serial tenfold dilutions of ADV DNA. The limit of detection (LOD) was approximately 10^2 genome copies per reaction, where amplification was consistently observed. Amplification below this threshold was inconsistent and not reproducible, defining the lower boundary of reliable detection.

A standard curve constructed from the serial dilutions demonstrated strong linearity across at least five orders of magnitude (10^2–10^7 copies). The slope of the curve was −3.32, corresponding to an amplification efficiency (E) of 100%, and the correlation coefficient (R^2) reached 0.998, indicating robust quantitative performance. Ct values increased proportionally with decreasing template concentration, confirming the dynamic range and reliability of the assay.

Overall, the EvaGreen-based qPCR assay using the iTOWER platform demonstrated high analytical sensitivity and specificity, consistent amplification efficiency, and excellent reproducibility across runs. The combination of these performance characteristics supports rapid, reliable detection of ADV DNA in clinical samples, making the method suitable for both diagnostic and epidemiological applications.

Conclusions. The EvaGreen-based real-time PCR assay developed in this study provides a rapid, sensitive, and specific method for the detection of Aujeszky's disease virus (ADV) DNA in clinical samples. The assay demonstrated superior analytical sensitivity compared to conventional virus neutralization tests, detecting low viral loads that may represent early-stage or latent infections. High specificity was confirmed through both heterologous virus testing and melting curve analysis, with no cross-reactivity observed with related herpesviruses.

Quantitative evaluation revealed excellent reproducibility and precision, with low coefficients of variation across replicates, a wide dynamic range spanning five orders of magnitude, and optimal amplification efficiency (100%) with strong linearity ($R^2 = 0.998$). The method requires no post-PCR processing, allowing rapid and reliable detection suitable for routine diagnostic workflows and large-scale surveillance programs.

Overall, the developed EvaGreen qPCR assay represents a robust tool for both qualitative and quantitative detection of ADV. Its integration into diagnostic and epidemiological surveillance frameworks can enhance early detection, improve disease control measures, and support One Health approaches to managing viral infections in animal populations.

References

1. Centers for Disease Control and Prevention. (2022). One Health basics. https://www.cdc.gov/one-health/basics/index.html

2. Mackay, I. M., Arden, K. E., & Nitsche, A. (2002). Real-time PCR in virology. Nucleic Acids Research, 30(6), 1292–1305. https://doi.org/10.1093/nar/30.6.1292

3. Mao, F., Leung, W. Y., & Xin, X. (2007). Characterization of EvaGreen and the implication of its physicochemical properties for qPCR applications. BMC Biotechnology, 7, 76. https://doi.org/10.1186/1472-6750-7-76

4. Mettenleiter T. C. (2000). Aujeszky's disease (pseudorabies) virus: the virus and molecular pathogenesis--state of the art, June 1999. Veterinary research, 31(1), 99–115. https://doi.org/10.1051/vetres:2000110

5. Müller, T., Hahn, E. C., Tottewitz, F., Kramer, M., Klupp, B. G., Mettenleiter, T. C., & Freuling, C. (2011). Pseudorabies virus in wild swine: A global perspective. Archives of Virology, 156(10), 1691–1705. https://doi.org/10.1007/s00705-011-1080-2

6. World Organisation for Animal Health. (2021). Manual of diagnostic tests and vaccines for terrestrial animals (8th ed.). https://www.woah.org/en/what-we-do/standards/codes-and-manuals/#chapter/?rid=298&volume_no=3&ismanual=true&language=102&standard_type=6&animal_type=7

7. Pomeranz, L. E., Reynolds, A. E., & Hengartner, C. J. (2005). Molecular biology of pseudorabies virus: Impact on neurovirology and veterinary medicine. Microbiology and Molecular Biology Reviews, 69(3), 462–500. https://doi.org/10.1128/MMBR.69.3.462-500.2005

8. Gerilovych, A. P. (2011). Eksperymentalne i teoretychne obgruntuvannia ta rozrobka zasobiv epizootolohichnoho monitorynhu, diahnostyky virusnykh khvorob tvaryn ta molekuliarno-henetychnoho typuvannia yikh zbudnykiv (ortomikso-, paramikso-, herpes-, tsyrko- ta pestyvirusna infektsii) [Experimental and theoretical substantiation and development of means of epizootological monitoring, diagnostics of viral diseases of animals and molecular genetic typing of their pathogens (orthomyxo-, paramyxo-, herpes-, circo- and pestivirus infections)] (Doctoral dissertation summary, National Scientific Center "Institute of Experimental and Clinical Veterinary Medicine"). Kharkiv, Ukraine.

Deutsche internationale Zeitschrift für zeitgenössische Wissenschaft

• • •

№133 2026

German International Journal of Modern Science

• • •

№133 2026

Deutsche internationale Zeitschrift für zeitgenössische Wissenschaft ist eine internationale Fachzeitschrift in deutscher, englischer und russischer Sprache.

Periodizität: 24 Ausgaben pro Jahr
Format - A4
Alle Artikel werden überprüft.
Freier Zugang zur elektronischen Version des Journals

German International Journal of Modern Science is an international, German/English/Russian/Ukrainian language, peer-reviewed journal.

Periodicity: 24 issues per year
Format - A4
All articles are reviewed.
Free access to the electronic version of journal.

- Edmund Holst (Salzburg) AT
- Michaela Meissner (Köln) DE
- Klara Amsel (Liège) BE
- Briana French (Cambridge) GB
- Joleen Parsons (Manchester) GB
- Dragomir Koev (Sofia) BG
- Stanislav Štěpánek (Praha) CZ
- Valeriya Kornilova (Kyiv) UA
- Dmitriy Aksenov (Lviv) UA
- Valentin Bragin (Moscow) RU
- Mirosław Bednarski (Warsaw) PL
- Daniela Villa (Florence) IT
- Mattia Molteni (Rome) IT
- Sylwia Krzemińska (Ljubljana) SI
- Käte Kraus (Vienna) AT
- Eleonora Lehmann (Berlin) DE
- Alexander Dressler (Marseille) FR
- Zdzisław Małecki (Warsaw) PL
- Adrián Borbély (Budapest) HU

- Edmund Holst (Salzburg) AT
- Michaela Meissner (Köln) DE
- Klara Amsel (Liège) BE
- Briana French (Cambridge) GB
- Joleen Parsons (Manchester) GB
- Dragomir Koev (Sofia) BG
- Stanislav Štěpánek (Praha) CZ
- Valeriya Kornilova (Kyiv) UA
- Dmitriy Aksenov (Lviv) UA
- Valentin Bragin (Moscow) RU
- Mirosław Bednarski (Warsaw) PL
- Daniela Villa (Florence) IT
- Mattia Molteni (Rome) IT
- Sylwia Krzemińska (Ljubljana) SI
- Käte Kraus (Vienna) AT
- Eleonora Lehmann (Berlin) DE
- Alexander Dressler (Marseille) FR
- Zdzisław Małecki (Warsaw) PL
- Adrián Borbély (Budapest) HU

Artmedia24

Anschrift: Industriestraße 8,74589 Satteldorf Deutschland.

E-mail: info@dizzw.com
WWW: www.dizzw.com

Chefredakeur: Reinhardt Roth

Druck: Einzelfirma Artmedia24, Industriestraße 8,74589 Satteldorf Deutschland

Artmedia24

Address: Industriestrasse 8,74589 Satteldorf Germany.

E-mail: info@dizzw.com
WWW: www.dizzw.com

Editor in chief: Reinhardt Roth

Printing: Artmedia24, Industriestrasse 8,74589 Satteldorf Germany.

Der Redaktionsausschuss der Zeitschrift ist nicht verantwortlich für die veröffentlichten Materialien.

Für den Inhalt der Artikel sind die Autoren verantwortlich
Die Meinung der Redaktion spiegelt nicht unbedingt die Meinung der Autoren wider.

Bei Nachdrucken muss die Zeitschrift zitiert werden.

Das Material wird im eigenen Wortlaut des Autors veröffentlicht.

Editorial board of journal is not responsible for the materials published there.

Authors are responsible for the content of articles.

Opinion of editorial board may not coincide with the opinion of authors.

In case of materials reprinting - link to journal is required.
Materials are publishing in author's edition.

ISSN (Print) 2701-8369

ISSN (Online) 2701-8377

Edition: № 133/2026 (July) – 133th

Passed in press in July 2026

Printed in July, 2026

Printing: Artmedia 24, Industriestrasse 8,

74589 Satteldorf, Germany.

© Artmedia24

© Deutsche internationale Zeitschrift für zeitgenössische Wissenschaft / German International Journal of Modern Science